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DEVOTED TO

SCIENCE AND THE MECHANIC ARTS

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THE SCIENCE OF NAVAL ARCHITECTURE.*

BY
DAVID WATSON TAYLOR, D.Eng.,
Chief Constructor, Chief of Bureau of Construction and Repair, United States Navy.

THE art of shipbuilding was undoubtedly developed at a very early stage of the history of the human race. The earliest record of a ship, as distinct from a boat, canoe, or other small craft, is found in Egyptian carvings of a date about 3000 B.C. But the science of naval architecture, like so many other branches of science, developed slowly, this science, as now accepted, being mainly a development of the last hundred years, we may almost say of the last fifty years.

The famous Swedish naval architect and shipbuilder, Henry de Chapman, published a treatise on shipbuilding in 1775. As late as 1820 we find Doctor Inman, the head of the Royal Naval College and School of Naval Architects in Portsmouth Dockyard, England, publishing a translation of Chapman for the instruction of English students of naval architecture. Chapman's work, so far as it deals with the science of naval architecture, consists largely of empirical rules, although it was far in advance of his day, and much of it is still applicable to sailing ships. In some respects his ideas were largely erroneous, an example being his theories regarding resistance of ships. In fact, it was not until a hundred years after Chapman's time that the science of naval architecture was enriched by sound theories concerning this important branch.

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* Presented at the Stated Meeting of the Institute held Wednesday, May 16, 1917, when Dr. Taylor received The Franklin Medal in recognition of "His fundamental contributions to the theory of ship resistance and screw propulsion, and of his signal success in the application of correct theory to the practical design of varied types of war vessels in the United States Navy."

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Dealing with the sailing vessels concerning which Chapman wrote, Ruskin said:

> "Take it all in all, a ship of the line is the most honorable thing that man as a gregarious animal has ever produced. By himself, unaided, he can do bettter things than ships of the line; he can do poems and pictures and other combinations of what is best in him. But as a being living in flocks and hammering out with alternate strokes and mutual agreement what is necessary for him in those places, to get or produce the ship of the line is his first work. Into that he has put as much human patience, common sense, forethought, experimental philosophy, self-control, habits of order and obedience, thoroughly wrought handiwork, defiance of brute elements, careless courage, careful patriotism, and calm expectation of the judgment of God as can well be put into a space 300 feet long and 80 feet broad, and I am thankful to have lived in an age when I can see this thing done."

This is what Ruskin thought and wrote years ago of the ship of his day. His words are even more true of the ship of our present day and generation. His 300 feet of length has trebled, and the size of such a ship, as measured in terms of weight, has grown nearly ten times. These modern ships have been made possible by the development of the science of naval architecture. This science, alone and unaided, without parallel development in practically all of the arts, sciences, and trades, could not have produced these ships; but, so far as the ship itself is concerned, all the great progress in every branch of science and industry could not have produced this concentrated embodiment of human intelligence without the development and advancement of naval architecture or the theory of shipbuilding, a branch of applied science which calls upon and draws from an exceptional number of the arts and sciences.

The modern battle cruiser, whose building is just being undertaken in this country, is an excellent example of the mutual agreement and coördination necessary between all the arts and sciences in the work of the naval architect. These vessels of ours will be of 35,000 tons displacement, and will be capable of a speed through the water of some 35 knots, or a little over 40 statute miles per hour. To drive this mass at this speed, there will be required a machinery installation capable of delivering 180,000 horsepower. The vessels are 850 feet in length; they will carry ten high-powered 14-inch guns as a main battery, with the addition of a large number of guns of smaller calibre, to say nothing of the torpedo tubes.

Let us consider very shortly a few of the sciences involved when we undertake to build such a vessel. It is hardly necessary to say that this undertaking would not have been possible without the slow, steady development, through the ages, of the various theorems of pure mathematics, which, in their applied forms, have been necessary to material progress in the various branches of engineering. In addition to its general application, mathematics has made possible the modern systems of control of the firing of the great guns, which permit them, with a considerable degree of accuracy, to drop a shell weighing a ton, on a comparatively small target, at a distance of 12 to 15 miles. This accurate control of fire is based largely on instruments or mechanisms which permit the instantaneous solution of problems containing as many as half a dozen variables.

Likewise, these ships could not be possible without the aid of astronomy, for it is through the development of that science, and through the experimental results made possible by it, that the various navigational instruments can be utilized to permit a sure and safe passage of the ship from one point of the earth's surface to another.

Chemistry has played its part, not only in its general contributions to all engineering progress, but also in its solution of specific questions and difficulties, such as are involved in the manufacture of propellent powders and high explosives in forms that may be safely handled and carried on such a vessel until the selected moment for turning loose their destructive forces. Chemistry, also, through its particular manifestation in the form of metallurgy, has played one of the most important parts, by providing numerous varieties of steel, ferrous alloys, and non-ferrous metals, which are used in the various parts of the ship and its equipment, many of these having been developed solely for the use to which they are put in such vessels as these.

Physics, in its various branches, has played a prominent rôle. In optics it has given us the theories of and has made practicable the various instruments which, in conjunction with fire control systems, make possible the accurate firing of guns and torpedoes, without which such a vessel would have no *raison d'être*.

Acoustics has played its part in the solution of many particular problems and difficulties, for, in the same way that coördination has been carried out in constructing the ship, the most complete and harmonious coördination of all parts of its organization is necessary in her hour of trial by battle. This is rendered possible only by the most perfect means and instruments of communication throughout all parts of the vessel. These systems of communication must be such that they will not break down in the midst of the noises and confusion of battle, or because of the high mental tension, at such times, of the personnel using them.

The sciences of physiology, medicine, and hygiene must likewise play their parts, for, during the long years of peace, each of these vessels must be the healthful and, as far as possible, the happy home for anywhere from 1000 to 1500 men. This means that what we term in the navy "berthing and messing" facilities, or what in civil life would be referred to as the "housing and feeding" conditions, must be based on the most modern scientific principles. Likewise, to insure efficiency in battle, the design must take careful cognizance of what these sciences have taught us as to the limitations of human endurance when working at high pressure under adverse conditions. Nor do we stop at this point, for there is provided, in addition, a completely equipped medical establishment or hospital, including operating-rooms, isolation wards for contagious diseases, special examining and treatment rooms, dental facilities, etc.

Without further enumeration of the many other branches of science and engineering which necessarily enter into the design of one of these great ships, let us consider more closely the principal branches of naval architecture proper. This is, broadly speaking, the division of engineering which enables us to make use of accumulated progress and knowledge to produce one workable and efficient assembled unit in the form of a ship. Its branches closely parallel the primary operations necessary in the design of such a ship, as has been described. Given the fundamental requirements of the design, which in the naval service we term military characteristics, and which consist of a brief statement of the results which it is desired to obtain with the completed vessel in service, it is first necessary to make an estimate of the size of the ship which will permit a solution of the design problem. The first estimate or approximation must be based largely on previous practice and experience. Before the development of naval architecture, in its modern sense, the necessity usually involved rather slow step-by-step progress from one ship to another. Naval architecture has now taught us how to make these steps much greater, so that during the last quarter of a century advances which would have been bold to rashness at an earlier time have become almost routine. The rule of step-by-step progress referred to above has at least one remarkable—we may almost say astonishing—exception. Some 65 years ago a famous English civil engineer and bridge builder turned to shipbuilding. Maintaining that the larger the ship the more economical and efficient her operation, Brunel attracted large capital and in association with Scott Russell, the shipbuilder and naval architect, finally produced the *Great Eastern,* which was indeed a giant by a pigmy when compared with the other iron steamships of her day. Her keel laid in 1854, launched in 1858 after many difficulties, and put in service in 1859, the *Great Eastern* was not a commercial success. She fell short of the expectations of her designers in many respects. The successful completion even in five years of such a vessel was truly a remarkable accomplishment, but her size was ahead of her day, and it was not until 1899 that we find it again reached. As already stated, progress is more rapid nowadays than heretofore, but even now naval architecture would hardly enable us to take, with confidence, such a leap as the *Great Eastern* promoters undertook.

When in the early stages of a design we have, based on previous practice and experience, reached a first approximation to the size of the vessel, it is next necessary to examine in detail the problems of strength, stability, resistance, and propulsion of the ship. These represent broadly the main divisions of our subject. Naval architecture, as a whole, and its branches, like engineering generally, has not yet become an exact science, and in some respects it appears impossible that this will ever be attained. The strength and stability of ships, for example, should be such as to enable them to withstand, under all conditions, the waves of the sea, but the latter are infinite in variety, and the attempt must be to provide for any manifestation arising from this variety. It is, therefore, not possible in a new problem to lay down an exact condition of water surface, and say that if our ship can stand this condition it can stand all others. The best we can do is to make an approximation of the most severe condition, based on previous accumulated experience and observation. There have been made many thousands of observations on sea waves, but there is yet no complete agreement in regard to their limiting characteristics, such as length, height, and the relations existing between these dimensions.

About the middle of the last century Rankine gave us the first complete mathematical theory of the formation and character of waves, known as the trochoidal theory; his result had, however, been largely predicted by Grestner more than sixty years before. Although Rankine's theory does not explain and is not entirely consistent with all phenomena of this nature, it is generally accepted to-day as a reasonable and convenient approximation of the facts, and it is usually upon stresses due to waves such as result from Rankine's theory that we have our determinations of strength of vessels.

We find that from the very beginning of practical shipbuilding the problem of strength was recognized in concrete form, for in the very first ship of which we have historical record its picture shows what we now term a " hogging " girder, which was provided to take the strains resulting from the variation between distribution of weight and distribution of buoyancy. It was the existence of these strains, and the fact that they increased with increase in length of ships, that operated to limit the length and, consequently the size of ships during the era of wooden shipbuilding, as it was then, and still is impracticable to develop the full strength in end connections between contiguous wooden members. The introduction of iron and steel, in conjunction with the development of methods and mechanisms for riveting, has made the modern ship possible. For many years the provision of the necessary strength depended largely on rule-of-thumb methods and step-by-step development from one ship to another. Such methods, of course, led, in the majority of cases, to one of two results: either deficiency of strength, or excess of strength. For any structure erected on shore, the latter fault is not necessarily a serious one, except from the point of view of cost. On a ship, however, too much material is almost as grave an error as too little, for every ship is built to perform some distinct service, and, as a floating body, can carry for all purposes only the equivalent of the weight of water which it displaces. Every pound which goes unnecessarily into the structure of the ship itself is a dead loss to the aim or object for which the vessel is designed. The modern theory of longitudinal strength for a vessel, as based on many years of observation and experiments, has its origin in the simple fundamental theories of strength of beams or girders. The ship's structure as a whole is considered as a built-up girder with upper and lower flanges and connecting webs. This girder is assumed to be supported on a wave of length equal to that of the ship. The height of this wave is assumed to have various relations to its length, depending upon the magnitude of that length, but for the majority of cases this relation is taken as one to twenty. This girder is then assumed to be supported in a manner represented by the buoyancy curve of the ship when floating on such a wave. The form of this buoyancy curve will, of course, vary with the position of the ship in relation to the crest and hollow of the wave, and in important strength calculations it is redrawn for at least two, and sometimes as many as six, positions. The loading of the girder is represented by the loading of the ship, including its own weight, that of permanent installations, such as propelling machinery, etc., and that of the variable or useful load carried. By successive integrations and the use of the simple beam formula we then arrive at the figures representing stresses and strains in the theoretical girder. Some experiments have been made from time to time, notably those of Biles in 1903, to check the accuracy of the results obtained by this method, but, due to the cost and magnitude of such experiments, there have never been collected sufficient data to enable us to say how accurately these results do represent the actual stresses in the ship in service. Accordingly, we are still largely dependent on comparing the figures obtained by this method for the new ship with those obtained by the same method for previous ships that have shown adequate strength in service.

Possibly due to the fact that our standard wave is not so steep as waves having the length of short ships, and steeper than waves having the length of long ships, it seems to have been thoroughly established by experience that, with the method outlined above, it is safe to allow larger stresses in large and long ships than in short and small ones. If, for instance, we find that by this method a small vessel in service shows satisfactory results when her figured standard stress is, say six tons in compression and eight tons in tension, and shows indication of weakness if these figures are materially exceeded, we would find that also in service a very large and long ship would show no signs of weakness with calculated stresses as high as ten tons in compression and twelve tons in tension. This principle appears to have been acted upon, though the scientific principles underlying it were not fully understood, even in the early days of iron shipbuilding. This was brought out about fifty years ago, when our modern methods of figuring strength were first applied to ships built in accordance with the then existing rules of the classification societies, with the result that the large ships of that day were found to have indicated stresses in extreme cases nearly five times as great as those found in small ships.

There are, of course, a very large number of strength problems involved locally in ships themselves, and therefore particularly within the province of naval architecture, but these are, after all, secondary when compared with the problem of the strength of the main structure.

Turning now to stability, which is the measure of the ability of a ship to remain upright or to return to the upright when inclined by an external force usually impressed by varying conditions of water surface, we find that the full and exact treatment of this branch is of quite modern origin. In the earliest day adequate stability was largely dependent on carrying ballast, and the amount and location of such ballast were determined by trial. In other words, except by following more or less closely the model of a previous vessel, there was no means of determining in advance whether a proposed design would result in a satisfactory stability condition.

About the middle of the eighteenth century the French mathematician, Bouguer, made a long step in developing the science of stability by developing the concept of the metacentre. In mathematical language, the metacentre is the centre of curvature of the locus of the centre of buoyancy of the vessel as it is inclined. As a practical proposition the metacentre is the limit above which we cannot locate the centre of gravity of the ship without having her initially unstable and unable to remain upright. The position in space of this imaginary point depends upon the geometrical form and the dimensions of the ship. Perhaps a homely illustration may clarify the matter. If you take an ordinary rocking-chair and attach a weight to it in such a manner that the centre of gravity of the chair and the weight is above the centre of curvature of the rocker, the chair will not stay put and will loll over and capsize. If the centre of gravity is materially below the centre of curvature of the rocker, which is the case when one sits in an ordinary rocking-chair, the chair will remain in a fixed position; if the rocker is very flat, resulting in a greater distance of the centre of gravity below the centre of curvature, the chair will be stiff and harder to rock or heel from the upright position. The metacentre of a ship corresponds very closely with the centre of curvature of the rocker as already described.

After Bouguer developed the conception and mathematical methods for calculating the position of the metacentre, Atwood carried the matter further by calculating the righting arm or lever, which, multiplied by the weight involved, measures the torque when a vessel is inclined. The metacentric conception applies only to initial stability with the vessel upright, and for many years appears to have been sufficient, particularly as applied to sailing ships, which were very much of the same general type, with comparatively small variations of general form, relative freeboard, etc.

Something more than fifty years ago, however, the loss of the *Captain* brought home very strongly to naval architects, particularly in England, the fact that there was another factor involved in stability. A distinguished English officer, Captain Cowper Coles, took up with enthusiasm the monitor idea, first developed by Ericsson in this country, and as a result of his campaign there was built in England a low freeboard vessel called the *Captain,* with turrets and also full sail power. Naval architects of the English Admiralty were not enthusiastic over the type. The vessel had much less metacentric height than the pure monitor type, but early reports and experience with her indicated that she would be a great success, until on the night of September 7, 1870, in the Bay of Biscay, with a moderate gale blowing, she capsized, with a loss of 481 lives, including Captain Coles himself. The vessel was perfectly safe until conditions were such that she heeled over enough to bring her deck edge well under water. After that her righting force rapidly decreased, and at a comparatively small heel became negative, resulting in capsizing. Under the weather conditions existing the force of the wind against the sails of the *Captain* was sufficient to heel her beyond the safety angle, and over she went.

The investigation into this disastrous occurrence brought out the fact that a vessel with a comparatively small metacentric height may be perfectly safe if it retains a righting tendency at a large angle of inclination—a feature associated primarily with high freeboard. On the other hand, a low freeboard vessel, with a comparatively short range of stability, may also be perfectly safe if its metacentric height and initial stability are very great, so that a large amount of work has to be done to incline the vessel throughout its comparatively short range of stability.

This whole question is now fairly well understood, and the naval architect is enabled to adjust his metacentric height as he will by varying proportions and dimensions of the ship to suit the position of the centre of gravity and type of vessel—all requiring very careful and detailed calculations. As a matter of fact, there are passenger vessels crossing the Atlantic in perfect safety with no initial stability, or even with a slightly negative metacentric height, their freeboard and shape giving them a range of stability of as much as 90 degrees.

Since the days of Fulton's first steamboat the design of vessels' hulls, on such lines as to give the minimum resistance in passage through the water at varying speeds, consistent with the other characteristics of the ship, has become increasingly important. This is well illustrated in the case of the new battle cruisers, to which I have already referred. To arrive at the most advantageous dimensions and form of hull, for purposes of the high speed desired, there were made and tested in the Model Tank, at Washington, upwards of twenty models, with the result that the resistance of the model finally adopted was nearly fifteen per cent. less than that of the first model tried.

I would particularly invite attention to the fact, however, that this was by no means due to improvement in shape of lines alone, but also to other changes which were adopted with some reluctance, but which it was known in advance would materially reduce the resistance. Experience in recent years has fully confirmed the conclusion drawn from Model Basin investigations that, for high-speed vessels, the length is a primary factor. In fact we know in the majority of cases of high speed vessels that we could reduce resistance by increasing the length. This usually involves, however, increased weight of hull and other objections. So that for large, fast vessels the naval architect usually adopts dimensions which do not give the minimum resistance for the displacement, but the best all-around result, considering the total weight, including both hull and machinery.

Men-of-war in particular are generally made relatively shorter than merchant vessels, for the reason that ordinarily they travel at a low speed, and the long vessel requires more power at low speed than the short vessel, and hence on a given endurance requires a greater weight of fuel. The merchant vessel, particularly the fast passenger vessel making its passages at top speed or thereabouts, must be economical at that speed.

A hundred years ago the ideas of ship resistance were entirely crude, the usual opinion being that the resistance was in proportion to the area of the cross-section of the vessel which had to be forced through the water. About the middle of the last century Rankine put forward a theory which went to the opposite extreme. His proposition was that in a well-formed vessel the resistance was entirely due to the friction of the surface against the water, and he developed a method for estimating this. Our modern ideas on this subject are due primarily to William Froude, the originator of modern experiments, which have been the most useful appliance of research in this line one could imagine. The "law of comparison," by which, from the resistance of a small model at low speed, we can closely estimate the resistance of a large ship at high speed, is commonly called by naval architects "Froude's Law." It appears to have been originated independently by Mr. Froude, although, as a matter of fact, it is a particular case of the general law of mechanical similitude, apparently first enunciated by Newton.

The resistance of ships by the Froude methods is regarded as made up of three elements: The friction of the surface, which, for low-speed vessels, may be as much as 90 per cent. of the total, and seldom falls below 50 per cent., even for very fast vessels; the wave-making resistance, due to the energy required to create and maintain a system of waves accompanying the motion of the ship through the water; and the eddy resistance, due mainly to eddies behind stern-posts, struts, and other appendages, and hence quite a small factor in the total. The "law of comparison" applies with great accuracy to the wave-making resistance, and with reasonable accuracy to eddy resistance. To frictional resistance it is not applicable, but Mr. Froude, by experiments on surfaces, established coefficients of frictional resistance which are used to this day, although for some time naval architects have felt that it would be desirable to revise these coefficients upon the basis of experiments on a large scale. The procedure we use at the present time in obtaining the lines for a ship is about as follows:

By the use of tables and curves which have been produced as the result of years of experiment at the Washington Model Basin, certain coefficients, representing a form of under-water body, are selected, as giving a close approximation to the best solution of the particular problem in hand. By the use of these coefficients we can arrive at approximation to the best dimensions for any particular ship, and by the further use of certain standard forms of waterlines can draw, with little difficulty, the lines of the vessel. From the same data we can obtain a close approximation to the resistance, at varying speeds, of a hull built from these lines. These steps permit of settling the broad general characteristics of the design. The lines so drawn are then sent to the Model Basin, where a model to exact scale is built and its resistance accurately measured at varying speeds. In important designs, as in the case of the battle cruiser, this model will receive many variations in shape and refinements of details until it appears probable that the minimum resistance for such a hull has been reached. The resistance curve obtained from the final model is then used as the basis of the design of the machinery plant and propellers for the vessel.

There are, of course, many other divisions and subdivisions of naval architecture which enable us to foretell with a considerable degree of accuracy the behavior of a vessel under the many different conditions which may be met in a varied career of service, as, for instance, the degree of punishment which a ship can stand before sinking, when subjected to attack by gunfire, submarine torpedo, and mine and aerial bomb. These are factors which hitherto the naval architect has not been required to consider as regards merchant ships. If present piratical methods of war at sea are to continue, the distinction between merchant and war vessels will necessarily disappear.

As regards vessels of war, experience to date has shown broadly that the science of naval architecture has provided ships which function as anticipated. The enormously destructive weapons of the day are able to destroy in time anything that floats, and without disparaging Mahan's dictum that "Good men in poor ships have always won over poor men in good ships," there is no doubt that good ships are essential even to the best men. Our ships are now to undergo the "trial by ordeal" of the features carefully and patiently planned in past years. May they prove worthy of the good men that man them! There is one final thought, however, which naval architects the world over feel to-day. The progress of late years, which has seemed rapid, will seem slow indeed by the side of the progress and development which must and will be made during the years just ahead of us.

The science of naval architecture, whether applied to vessels of war or peace, has a weighty part to play as the world undertakes to meet the changed conditions of war time and of the time after the war.

Zirconia, a New Refractory Product. ANON. (*La Chronique Industrielle,* vol. 40, No. 291, p. 8, May 2, 1917.)—The attention of electro-metallurgists has recently been directed to the value of zirconia or oxide of zirconium, whose refractory properties appear to be applicable to electric furnaces. Free zirconium exists in three forms: amorphous, crystalline, and graphitic. The crystalline form, with a density of 6.4, has a melting-point of approximately 2350° C. Only two minerals can be considered as commercial sources of zirconium: the natural oxide and the silicate. Natural zirconia contains 84 per cent. of the pure oxide, with 8 per cent. of silica and 3 per cent. of oxide of iron. Purified, zirconia is a white substance with a density of 5 and, according to Weiss, a temperature of fusion of 3000° C.

The first important application of the oxide of zirconium was as a substitute for the cylinders of chalk in the Drummond light. This oxide was employed in the manufacture of incandescent gas mantles, but was later superseded by thorium oxide, which gives equally good results at lower temperature. Another application was effected in 1887 in the production of the Nernst lamp. Mixed with 10 per cent. of magnesia, with a binder consisting of starch, phosphoric acid, and glycerin or its borates, a product is obtained impermeable to liquids and unaffected by strong or fused alkaline mixtures. Its uses in metallurgy are very promising. In trials of a Martin furnace in a steel works at Remscheiden, Germany, a lining of zirconia was found in good condition after a run of four months, and apparently capable of another four months' service without repair.

Preliminary Study of the Alloys of Chromium, Copper, and Nickel. D. F. MCFARLAND and O. E. HARDER. (*Bulletin No. 93, Engineering Experiment Station of the University of Illinois.*)—The growing interest in special acid-resisting alloys and the many uses found for them have stimulated both the search for efficient materials of this nature and the study of the underlying causes of their inertness. Previous studies at the University of Illinois have shown that the almost perfect insolubility of certain alloys in nitric and other acids seems to be conditioned upon a proper mixture of chromium, copper, and nickel, together with smaller quantities of such added metals as tungsten or molybdenum.

As a result of further studies, methods have been developed for making castings of alloys of chromium, copper, and nickel. Twenty-one binary and thirty ternary alloys have been prepared, and physical and chemical tests have been made to determine the properties of the various alloys. More than 300 corrosion tests have been made to measure the effects of acids upon metals. In general, the results indicate that certain of the alloys of chromium, copper, and nickel give promise of becoming of great commercial importance not only in the construction of laboratory apparatus, but also in manufacturing and chemical processes in which the handling of acids is involved.

Copies of Bulletin 93 containing the results of these tests may be obtained gratis from C. R. Richards, Director of the Engineering Experiment Station, Urbana, Ill.

Reducing Prints on Printing-out Paper. ANON. (*Revue Scientifique,* vol. lv, No. 7, p. 209, March 24–31, April 7, 1917.)—Many formulas for the reduction of over-dense photographic negatives have been published, while the reduction of prints has seemingly aroused little interest. Nevertheless, the operation has value in the latter field, particularly when the prints are of large size and the paper is of a costly grade. The method employed is applicable to old prints, as it is necessary to work with a toned washed-and-dried print. The print is immersed into a solution of water, 100; hyposulphite of soda, 10; one per cent. solution of bichromate of potash, 3. Reduction begins at once and proceeds evenly. When the print is sufficiently reduced, it is thoroughly washed and dried. Most papers so treated retain their original color, though a few braids have a tendency to assume a blue-violet tone. The formula gives good results with gelatin papers. Collodion papers require a somewhat different treatment. The untoned print is washed and then immersed in a solution of water, 100; one per cent. solution chloride of gold, 1; hydrochloric acid, 1. The image at first appears to become spotted, but after a few minutes the reduction takes place evenly, while the toning proceeds normally, the color gradually changing from a brick-red to purple. When the image is sufficiently reduced, the print is fixed in a five per cent. solution of hyposulphite of soda. The tone is not altered either in fixing or drying, and the prints are of fine color and are permanent.

MODERN DYNAMO ELECTRIC MACHINERY.*

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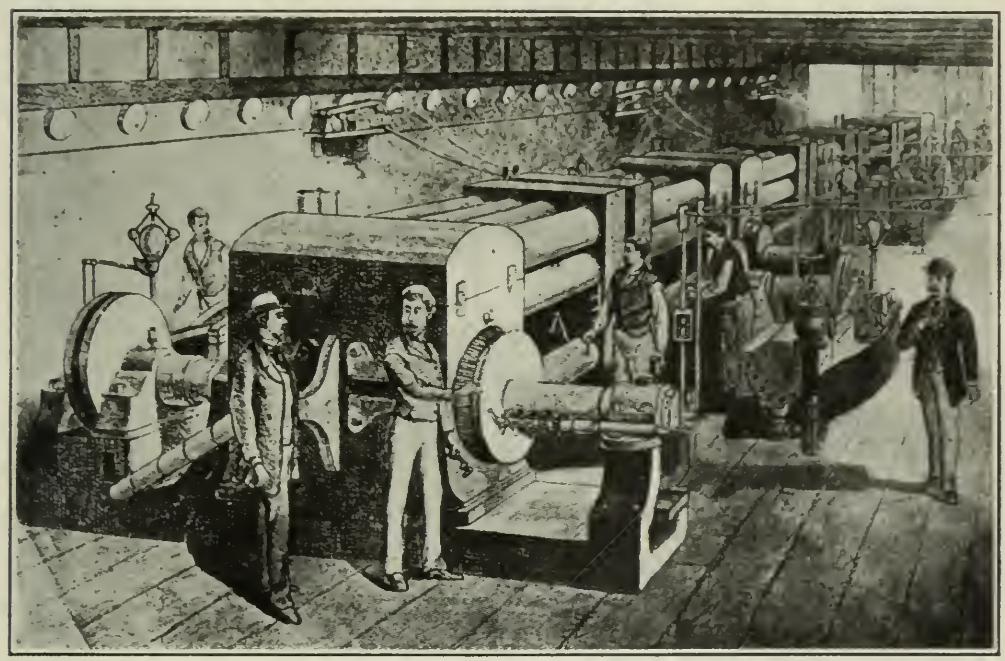
INTRODUCTION.

In few fields of human endeavor has there been such remarkable progress in the last thirty years as in electrical engineering. It is true that eighty-six years have elapsed since the principle of magneto-electric induction was discovered by Faraday, and that this discovery was immediately followed by the production of electric generators in large variety, which by 1865 were no longer mere laboratory machines, nevertheless these generators did not begin to assume great commercial importance until about 1880, by which time electric lighting had taken such a hold as to warrant the construction of central stations. Two of these early stations, installed in 1882, are shown in Figs. 1 and 2. The

Fig. 1.



Generating station of 1882 with 125-horsepower, direct-connected units. The parallel field coils and the forced ventilation are of interest.

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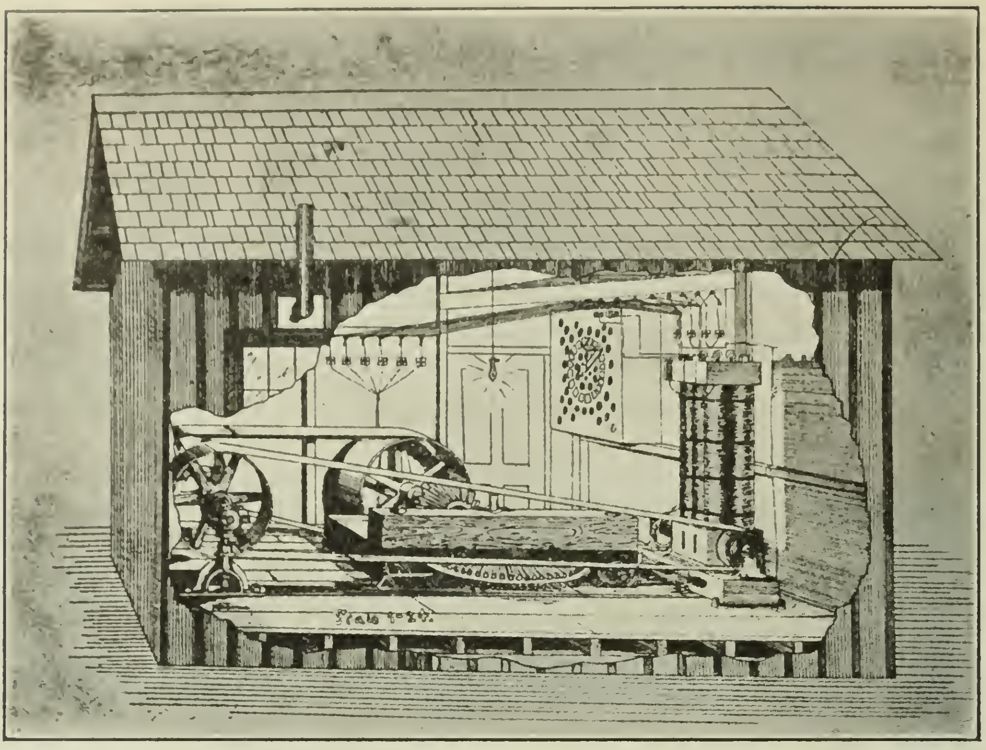
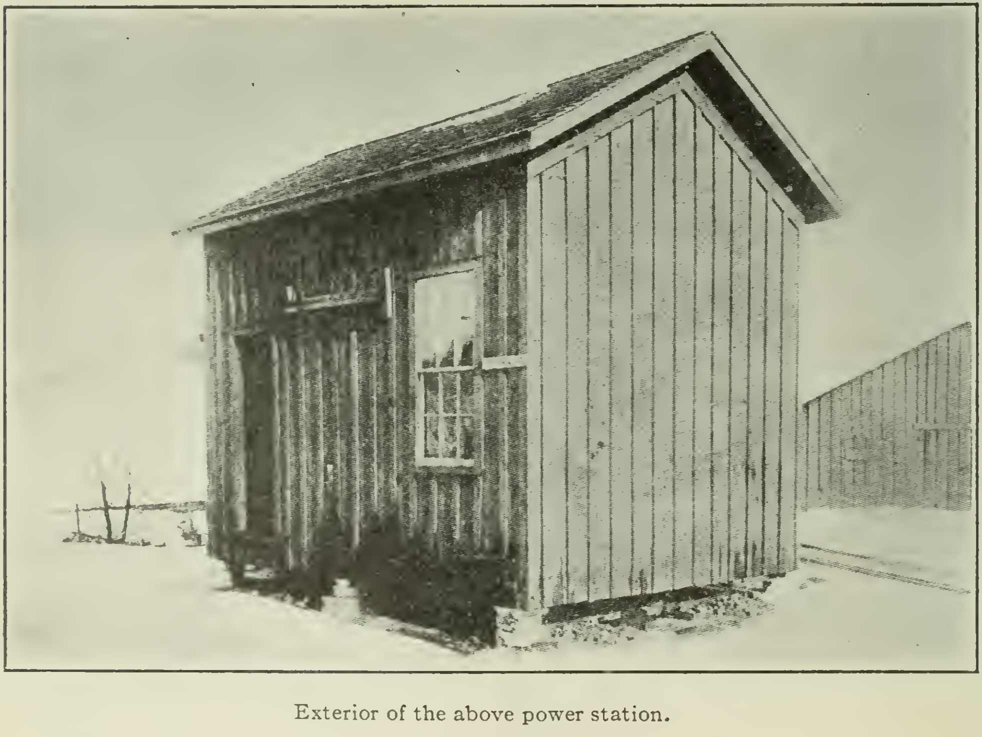
* Communicated by the Author. Based on a paper presented at a joint meeting of the Electrical Section and the Philadelphia Section, American Institute of Electrical Engineers, held Thursday, February 8, 1917.

FIG. 2.



Hydro-electric station of 1882 with a connected load of 250 incandescent lamps. The long poles and the parallel field coils are now obsolete.

FIG. 2A.

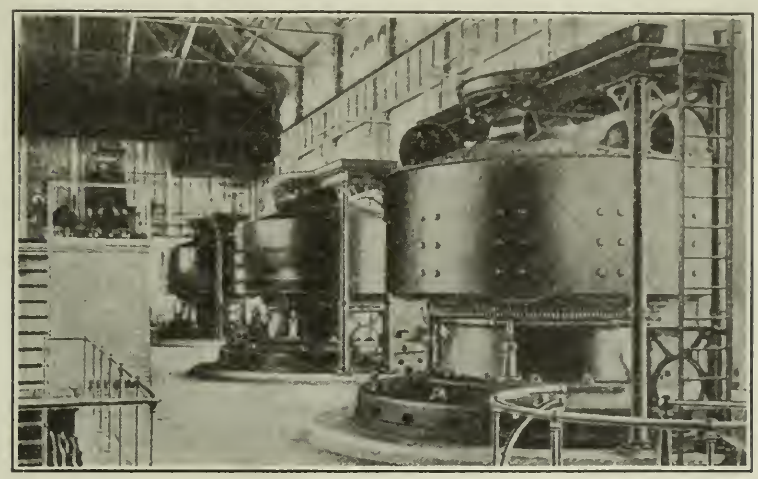


Exterior of the above power station.

Pearl Street station of the Brooklyn Edison Company started operation with a connected load of 2323 incandescent lamps, and the generators, which were direct connected and had a capacity of 125 horsepower, were considered so large in those days that they were generally known as Edison Jumbos.[1] The hydro-electric station at Appleton, Wis., was much smaller and had a connected load of only 250 lamps.

The great expansion in electric lighting which started about 1886 led to a gradual increase in the size of the central station, while the size of the individual unit increased from the 125-horsepower machines of 1882 to the 800-kilowatt units installed by the Brooklyn Edison Company in 1891,[2] and the 1500-kilowatt unit exhibited at the World's Fair in Chicago in 1893.[3] These machines were all direct connected and helped to make that practice standard; most of the early stations had high-speed generators belted to slow-speed engines, and the most conspicuous things in some of these early stations were leather, static, and stray fields.

FIG. 3.



First Niagara station with its 4000-kilowatt units. These machines were in operation only 13 years after the installation of the machine shown in Fig. 2.

By 1900 the design of direct-current machines had become somewhat standardized, the various criteria for a good design having become pretty well understood. With that date as a starting point, we shall show how the output for a given amount of material has gradually increased as the accumulated test data on actual machines allowed designers to work closer to the limits, while the gradual introduction of interpoles, which has led to a new conception of what is meant by sparkless commutation, has made it possible to build machines to carry overloads, operate at high speeds and through a wide range of speed in a way that most people considered impossible only ten years ago.

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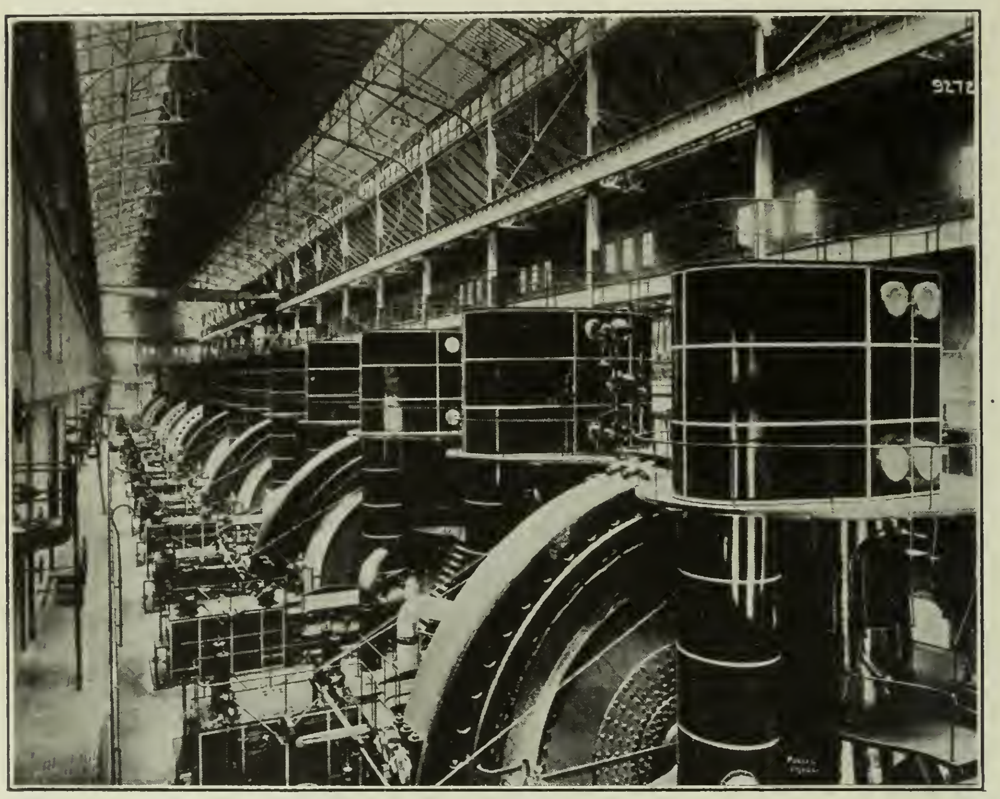
[1] "History of the Brooklyn Edison Company," *Electrical Engineering*, New York, vol. 21, p. 25.

[2] "History of the Brooklyn Edison Company," *Electrical Engineering*, New York, vol. 21, p. 25.

[3] For data on this machine, see "Electric Generators," by Parshall and Hobart, published 1900.

FIG. 4.

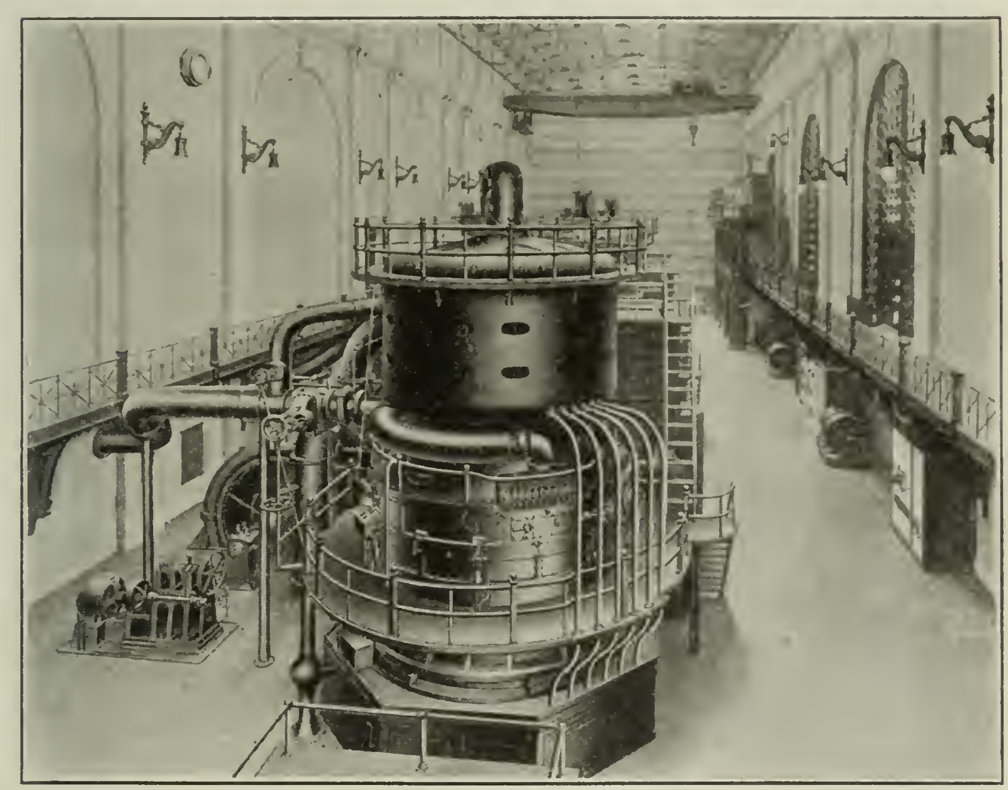


The Manhattan generators, designed in 1899. At the time of their erection they were the largest engine-driven dynamos that had ever been built.

The early central stations were built to supply direct currents, but, as the radius of distribution gradually extended, the subject of alternating currents forced itself on central station engineers. In 1886 the Westinghouse Company began the development of alternating-current machinery; in 1888 the induction motor was invented; in 1890 the Telluride Company transmitted power economically for a distance of fifteen miles, and in 1895, only thirteen years after the Appleton station had been installed, the water was turned into the 4000-kilowatt units of the first Niagara station.

The size of the alternating-current generator kept on increasing, and at the time of their erection in 1901 the machines shown in Fig. 4 were the largest engine-driven dynamos that had ever been built. These machines are of a type that has been entirely superseded by the turbo-alternator, which began to make itself felt as early as 1903, when the 5000-kilowatt vertical Curtis turbo units shown in Fig. 5 were installed by the Commonwealth Edison Company of Chicago. Turbo-generators now under construction include a single machine of 45,000 kv.a. capacity, also a 70,000-kv.a. three-machine unit which has one high- and two low-pressure turbine wheels, each direct connected to its own generator.

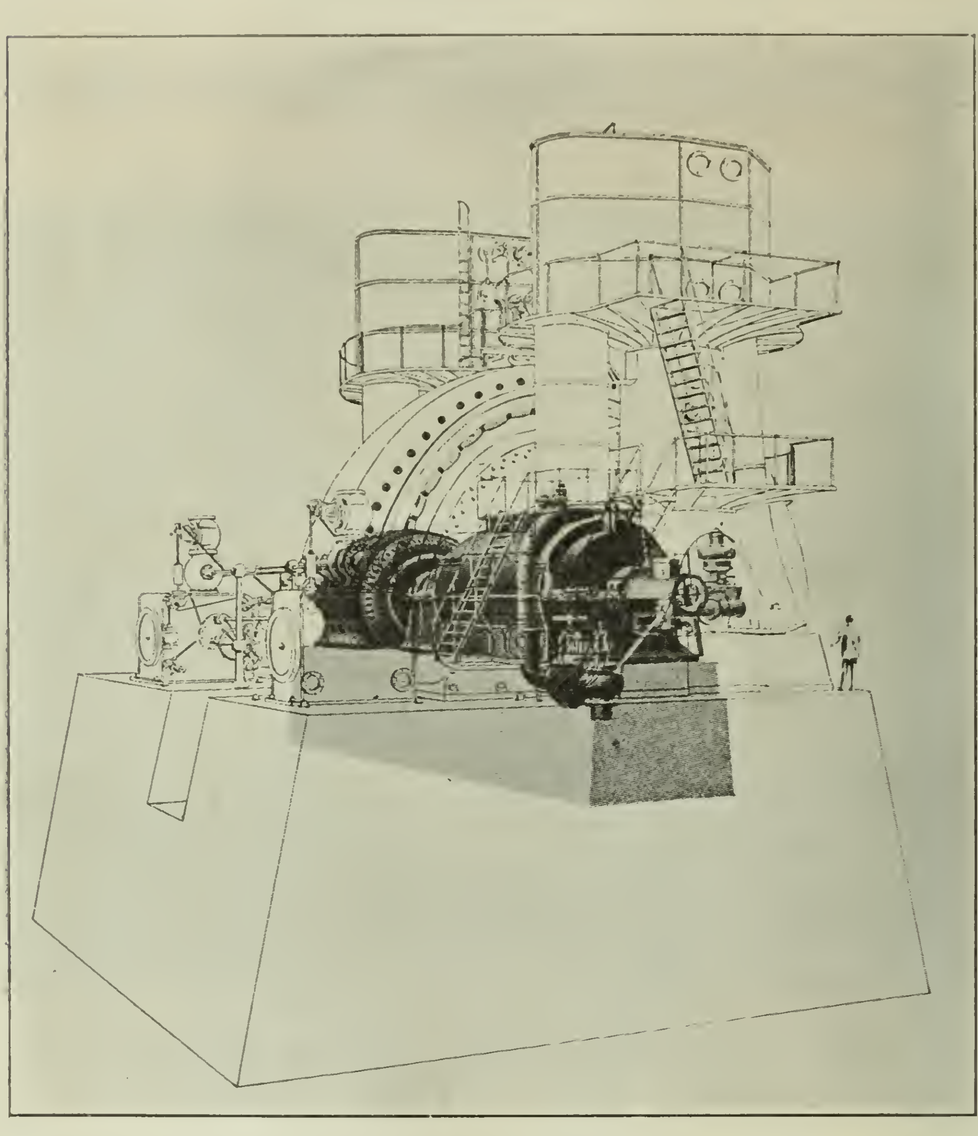
FIG. 5.



The first Curtis turbo-alternator of 5000 kilowatts capacity. It was installed by the Commonwealth Edison Company of Chicago in 1903.

One of the great advantages of the turbo alternator is well shown in Fig. 6, and since this picture was taken, the output for a given size of machine has been more than doubled. This latter development, which will be studied in greater detail, while partly due to improvements in ventilation, has been almost entirely due to the use of mica insulation and to the development and gradual introduction of a satisfactory voltage regulator.

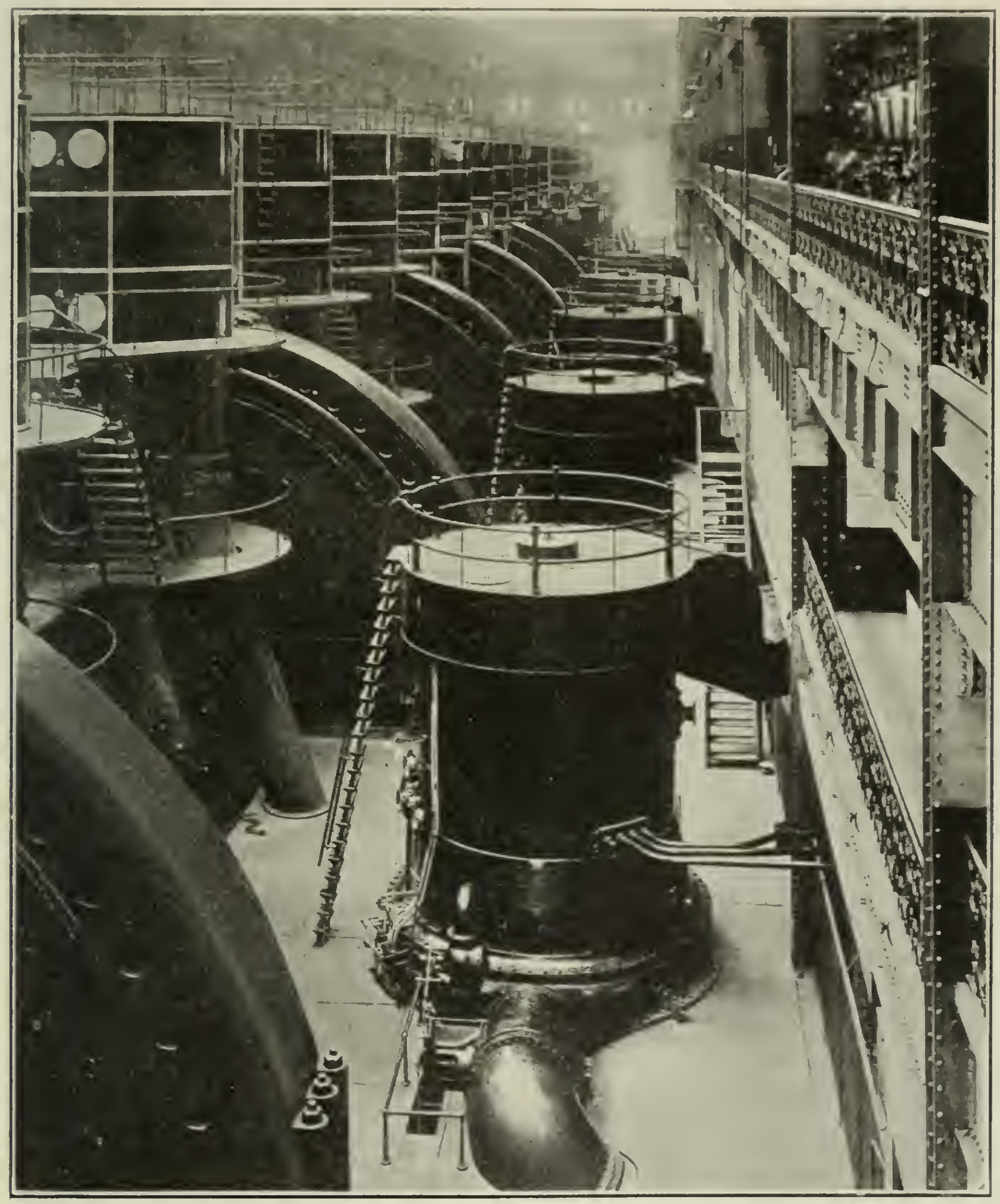
FIG. 6.



Relative dimensions of an engine-driven alternator and of a turbo-alternator of the same capacity.

Another type of machine on which remarkable progress has been made in the last ten years is the 60-cycle rotary converter. Up until 1909 the record of these machines was so poor that few manufacturing companies would undertake their construction, while most operating engineers preferred motor-generator sets. To-day, however, satisfactory 600-volt, 60-cycle rotaries can be had of 2500-kilowatt capacity at 400 revolutions per minute. This result, as we shall see later, has been made possible in a large measure by improvements in the manufacture of high-speed commutators and by the addition of interpoles to make high-speed commutation satisfactory.

FIG. 6A.

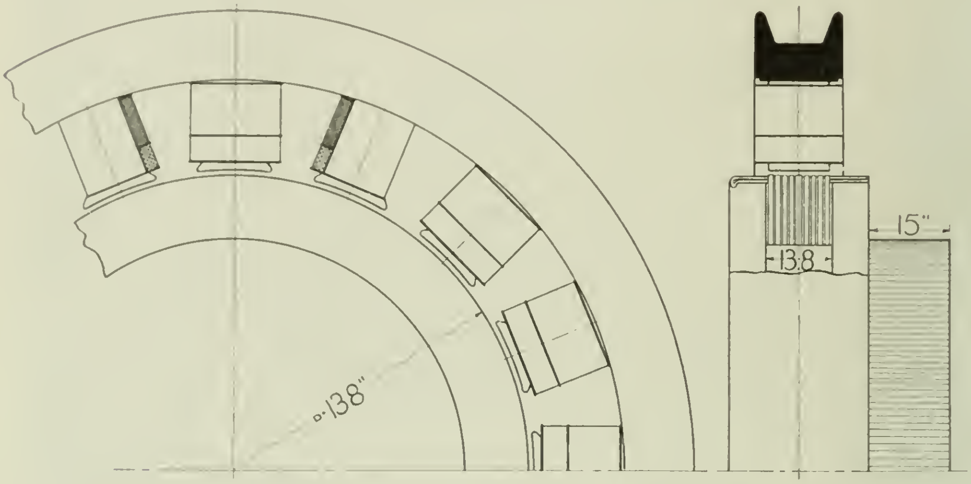


Engine-driven generators of 5000 kv.a. at 75 r.p.m. installed in 1901, and Curtis low-pressure turbo-alternators of 7500 kv.a. capacity installed in 1909.

RECENT DEVELOPMENTS IN DIRECT-CURRENT MACHINERY.

It has already been pointed out that the design of direct-current machinery had become somewhat standardized by 1900.[4] In the following year a well-known machine was built from designs furnished by Hobart, the important constants of which are given in Table I and the principal dimensions in Fig. 7. Since this machine represents the best practice of that time, it will be well to examine it carefully to find out why the output was limited to 1000 kilowatts.

FIG. 7.



Hobart's generator of 1901. Capacity 1000 kilowatts, 500 volts, 90 r.p.m.

TABLE I.

Kilowatts	1,000
Volts, no load	500
full load	500
Ampères	2,000
Revolutions per minute	90
Poles	16
Slots per pole	24
Size of slot	0.53 inch x 1.26 inch
Conductors per slot	6
Size of conductor	0.11 inch x 0.49 inch
Type of winding	One turn per coil, multiple
Tooth/slot	1.13
Maximum tooth density at no load	142,000 lines/square inch
Core	59,500 lines/square inch

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[4] For an account of the early history of electrical machinery, see "Dynamo Electric Machinery," by S. P. Thompson.

For an account of the engineering evolution of direct-current machines in America, see Lamme, *Electric Journal,* vol. 12, pp. 65, 115, 164, 212.

TABLE I.—(*Continued*)

Pole	92,000 lines/square inch
Yoke	64,000 lines/square inch
a. Ampère conductor per inch of periphery	665
b. Circular mils per ampère	550
Ratio *a/b*	1.21
Peripheral velocity of armature	3,250 feet per minute
c. Ampère turns for tooth and gap at full load	9,300
d. Armature ampère turns per pole	9,000
Ratio *c/d*	1.04
Air-gap clearance	0.4 inch
Pole enclosure	71 per cent.
Commutator segments	1,152
Commutator segments covered by brush	2.72
Current density in brush contact	32 ampère/square inch
Average reactance voltage	2.5

The output might have been increased by increasing the flux per pole, but this would have necessitated wider teeth and therefore narrower and deeper slots, because the flux density in the teeth has already reached the high value of 142,000 lines per square inch. The output might also have been increased by increasing the current rating of the machine, which, of course, would have necessitated conductors of larger cross-section to carry the current and deeper slots in which to carry the conductors. Why, then, was the slot depth limited by Hobart to 1.26 inches, and why, in those days, was the criterion of a good design that the slots be wide and shallow?

COMMUTATION AND REACTANCE VOLTAGE.—It was early recognized that for satisfactory commutation the brush contact resistance should be large and the voltage of self-induction of the coils undergoing commutation should be small. The first satisfactory method by which an approximation to the value of this voltage of self-induction could be obtained was given by Hobart,[5] who developed a formula somewhat as follows:

The flux linking the coil *M,* Fig. 8, due to the currents that are being simultaneously commutated in the short-circuited coils, is

$$\begin{aligned}\phi_a &= (\phi_s \times 2T \times 2L_s \times I_c) + (\phi_e \times T \times 2L_e \times I_e)\\ &= 2T\, I_c\, (2\phi_s \mathrm{L}_s + \phi_e \mathrm{L}_e)\end{aligned}$$

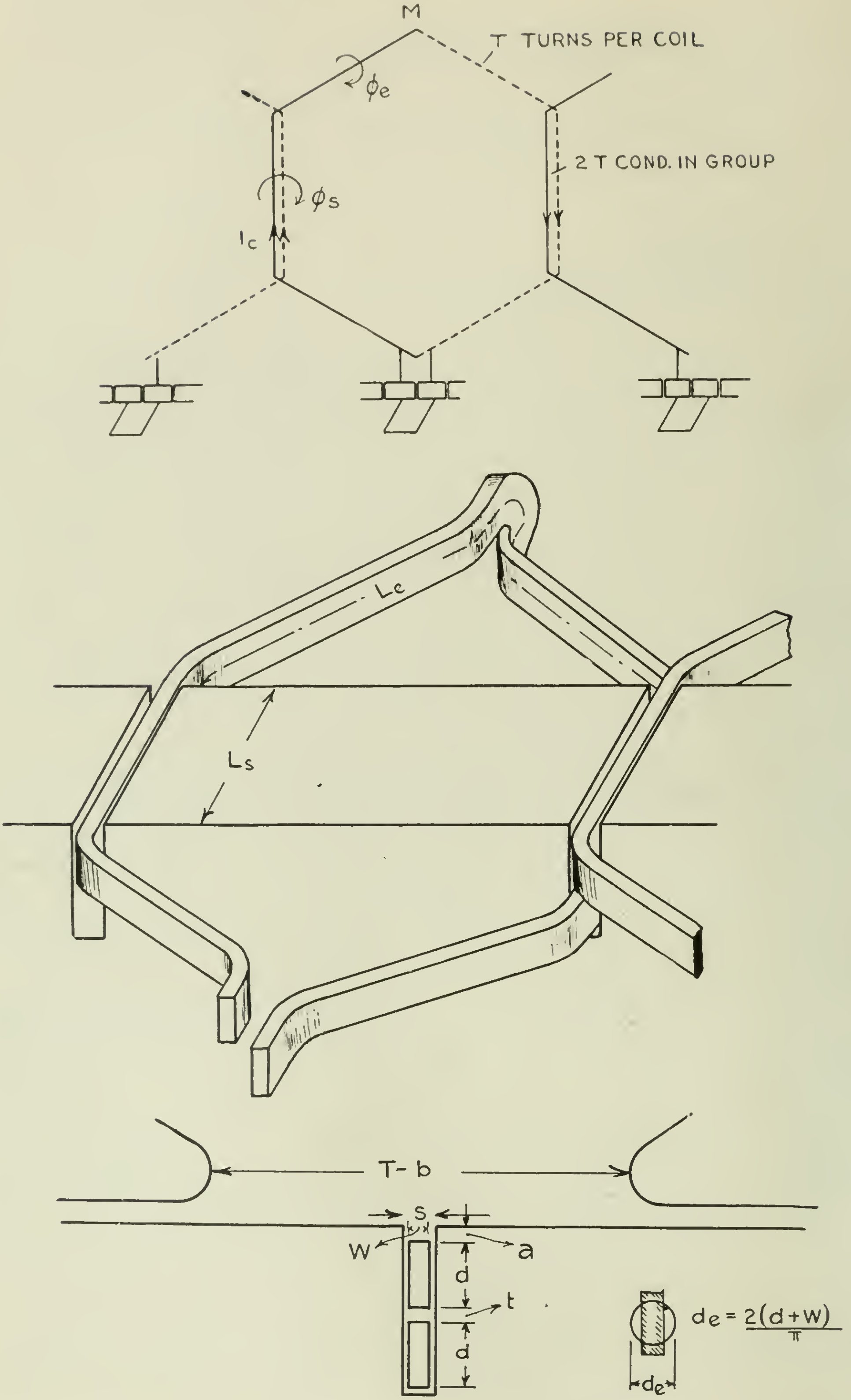
where ϕ_s is the number of lines that circle 1 inch length of the embedded part of coil *M* for each ampère conductor in the group of conductors that are simultaneously undergoing commutation.

---

[5] "Modern Commutating Dynamo Machinery," *Journal of Institute of Electrical Engineering,* vol. 31, 1901.

See also "A Theory of Commutation by Lamme," *Trans. of A. I. E. E.,* vol. 30, 1911 (p. 2359).

FIG. 8.



Commutation of the current in a full pitch winding.

ϕ_e is the number of lines that circle 1 inch length of the end connections of coil M for each ampère conductor in the group of end connections that are simultaneously undergoing commutation.
T is the number of turns per coil.

This flux is reversed in a time of $T_c = \frac{1}{SR}$ second,

where S is the number of commutator segments.
R is the speed of the machine in revolutions per second,
so that the average voltage of self- and mutual induction generated in coil M is

$$RV_{av} = \frac{2\phi_a}{T_c} \times T \times 10^{-8}$$
$$2\phi_a \times T \times R \times S \times 10^{-8}$$
$$= 4T^2 I_c RS(2\phi_s L_s + \phi_e L_e) 10^{-8} \text{ volts.}$$

For standard machines Hobart has found by experiment that ϕ_s is approximately equal to 10 lines and ϕ_e to 2 lines of force, also that RV_{av}, as calculated by the above formula, should not exceed 2.5 volts.[6]

In the given machine we find

$S = 1152.$
$R = 15$ revolutions per second.
$I_c = 2000/16 = 125$ ampères.
$L_s = 13.8$ inches.
$L_e = 43$ inches.

Also, that the brush covers 2.72 commutator segments, so that at certain instants three adjoining coils are simultaneously undergoing commutation.

Therefore,

$$RV_{av} = 4 \times 125 \times 15 \times 1152 \; (2 \times 10 \times 13.8 + 43 \times 2) \times 10^{-8} \times \frac{3}{2.72}$$
$$= 3.42 \text{ volts.}$$

Values of ϕ_s and ϕ_e more nearly accurate may be computed by the aid of the formulæ given by Arnold,[7] the first of which formulæ shows the effect of slot depth on reactance voltage:

---

[6] Hobart makes the assumption that the current reversal during commutation follows a sine law, and the reactance voltage, as he defines it, is $\pi/2$ times the value given by the above formula.

[7] "Die Gleichstrommaschine," vol. i, pub. 1906, p. 397.

$$\phi_s = \frac{2.54 \times 4\pi}{s \times 10}\left[\frac{d}{1.5} + \frac{t}{4} + a + .73s \log_{10}\left(1 + \frac{\pi(\tau - b)}{2s}\right]\right. \text{ (see Fig. 8).}$$

$$= 6.1$$

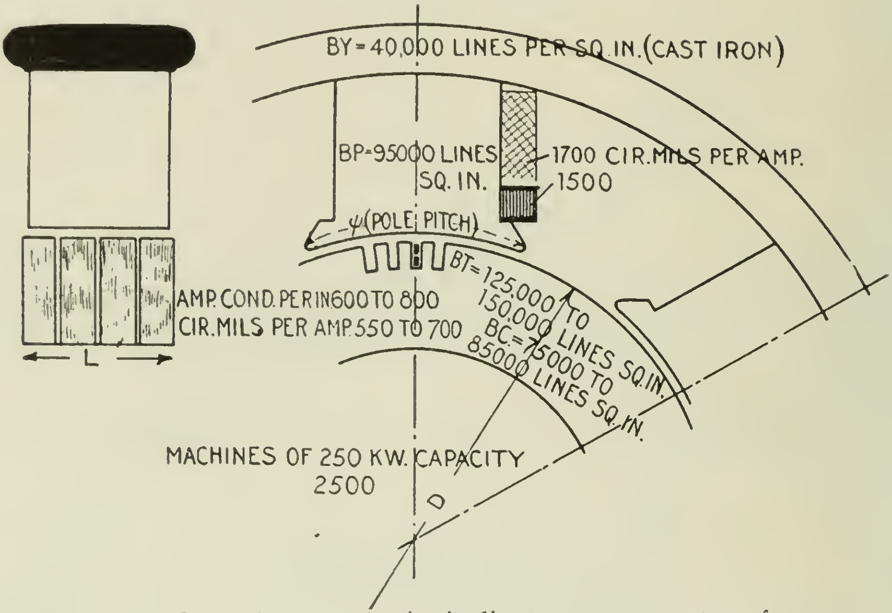
$$\varphi_e = 2.54 \times .46\left(\log_{10}\frac{L_e}{d_e} - .2\right).$$

$$= 2.16$$

$RV_{av} = 2.5$ volts.

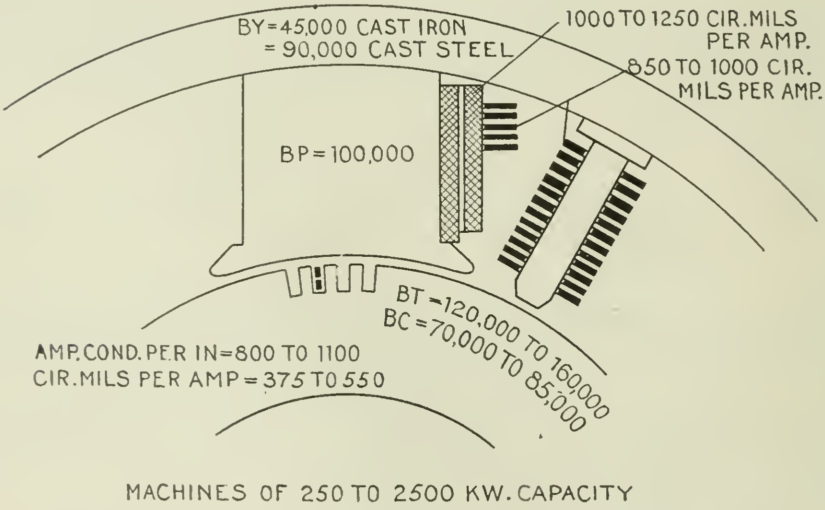
This value of reactance voltage is already close to the safe limit, so that it would not have been advisable to have made the

FIG. 9.


BY=40,000 LINES PER SQ. IN. (CAST IRON)
BP=95000 LINES SQ. IN.
1700 CIR. MILS PER AMP.
1500
ψ(POLE PITCH)
BT=125,000 TO 150,000 LINES SQ.IN.
BC=75000 TO 85000 LINES SQ.IN.
AMP. COND. PER IN 600 TO 800
CIR. MILS PER AMP. 550 TO 700
L
MACHINES OF 250 KW. CAPACITY
2500
D

Limits of flux and current density in direct-current generators of 1907.

FIG. 10.


BY=45,000 CAST IRON
=90,000 CAST STEEL
1000 TO 1250 CIR. MILS PER AMP.
850 TO 1000 CIR. MILS PER AMP.
BP=100,000
BT=120,000 TO 160,000
BC=70,000 TO 85,000
AMP. COND. PER IN=800 TO 1100
CIR. MILS PER AMP=375 TO 550
MACHINES OF 250 TO 2500 KW. CAPACITY

Limits of flux and current density in direct-current generators of 1917.

slots deeper or to have attempted the reversal of a larger current.

In an endeavor to improve commutation the brushes in these early machines were placed in such a position that the short-circuited coils were under the pole tips and in a magnetic field of such value as to cause a voltage to be generated in them equal and opposite to the voltage of self-induction. The strength of this reversing field should increase directly with the current to be commutated, but, due to armature reaction, it actually decreases as the load on the machine is increased. To minimize this effect of armature reaction the air-gap must be made reasonably large to cut down the cross-field, and then a sufficient number of ampère turns put on the poles to send the main flux across the air-gap, so that another criterion for the sparkless commutation of the type of machine built in 1900 was that the ampère turns on the main pole required to send the flux across the gap and tooth part of the magnetic circuit should be at least twenty per cent. greater than the armature ampère turns per pole. By this means a fairly stiff field was found under the pole tip even at full load, and the usual practice was to shift the brushes as far into this field as possible without causing sparking at no-load, and to rate the machine at that load which did not cause sparking in this position.

Limitations in Design in 1907.—Let us now tabulate the limitations in design as recognized by designers ten years ago. The reader will find it of interest to compare the figures with those that were adopted by Hobart in 1901. These limitations, given in Fig. 9, are as follows:

Permeability which limits the flux density to

95,000 lines per square inch in the pole cores.
40,000 lines per square inch in cast iron yokes.
90,000 lines per square inch in cast steel yokes.
150,000 lines per square inch in armature teeth.

Higher densities would indeed allow a corresponding reduction in the cross-section of the yoke and core, but this would be at the expense of the increased copper required for the additional excitation.

Core Heating.—This is kept down to a reasonable value by limiting the tooth and core densities to approximately the following values:

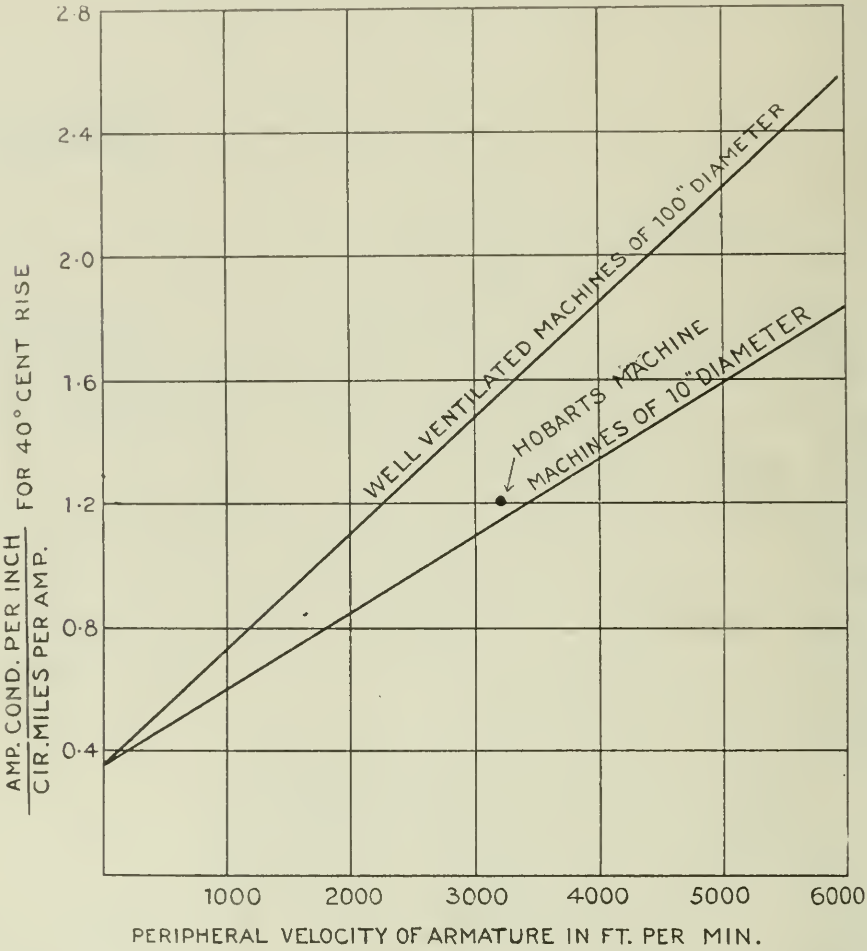
Maximum tooth density = 150,000 lines per square inch below 30 cycles.
125,000 lines per square inch at 60 cycles.
Average core density = 85,000 lines per square inch below 30 cycles.
75,000 lines per square inch at 60 cycles.

Copper Heating.—The copper loss to be dissipated by each inch of armature periphery is proportional to the ratio

$$\frac{\text{ampères per conductor} \times \text{conductors per inch of periphery}}{\text{circular mils of copper section per ampère}}.$$

The higher the peripheral velocity of the armature, the higher can be this ratio. Safe values for large machines are given in Fig. 11.

FIG. 11.



Heating curves for armature and connections (1910); values 20 per cent. higher are often found in machines of 1917.

Commutation.—As already pointed out

Ampère turns (gap + tooth) > 1.2 (armature ampère turns per pole);

also the reactance voltage

$$RV = 4T^2 I_c RS(20L_s + 2L_e)10^{-8}$$

should not exceed 2.5 volts, unless the commutating field is stiffer than usual or the brushes of higher contact resistance. A comparison between Figs. 9 and 10 will be found of interest.

THE OUTPUT EQUATION.—It will be advisable at this point to pick out the factors on which the output directly depends and find out wherein they are limited.

Watts output = volts per conductor x ampères per conductor x πD (conductors per inch of periphery).
= (lines cut per conductor per second x 10^{-8}) x πDq (see Fig. 9).

Therefore $$\frac{\text{watts}}{\text{r.p.m.}} = \left(\frac{B_g\psi}{6.08 \times 10^8}\right) D^2L$$
$$= KD^2L$$

where K is called the output constant.
D is the armature diameter in inches.
L is the axial length of the core in inches.
B_g is the apparent gap density in lines per square inch
ψ is the per cent. pole enclosure = pole arc/pole pitch.
q is the ampère conductors per inch of periphery.

The fact that the heating of the armature depends on the value of q, the ampère conductors per inch, has already been pointed out; its further importance is emphasized by S. P. Thompson, who states: "If the design is such that not more than 200 ampères are to be collected at any one set of brushes, if the average flux density in the gaps is not less than 40,000 lines per square inch, and if the teeth are well saturated, the machine will run sparklessly if the number of ampère conductors does not exceed 650 per inch of the periphery of the armature." [8]

It has been customary to plot values of K against kilowatt output as in Fig. 12. These curves show how the output factor has increased in the last thirteen years; the reasons for this increase we shall now discuss.

The value of B_g is limited by the permissible value of the tooth density, so that the greater the ratio of tooth/slot the larger the permissible value of B_g. This ratio seldom exceeds 1.10 in the non-interpole type of machine, and a larger value can be obtained only by the use of deep slots, which generally results in poor commutation. Average values of B_g for frequencies up to 30 cycles are given in Fig. 13; at higher frequencies the values are somewhat less. The smaller the armature diameter the greater the tooth taper and the lower the gap density for a given density at the root of the teeth.

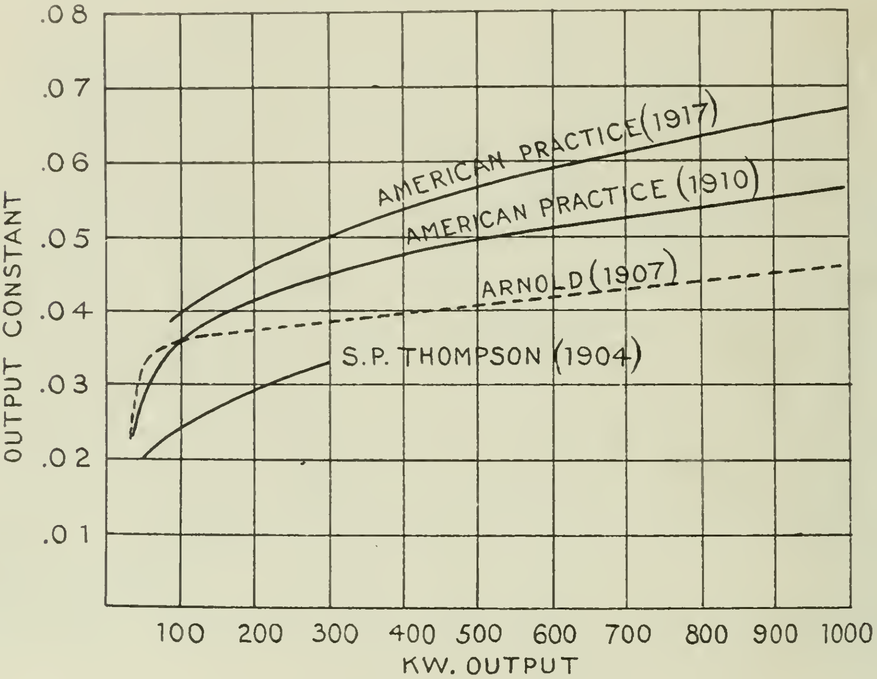
---

[8] "Dynamo Electric Machinery," vol. i (published 1906), p. 276.

The value of q, the ampère conductors per inch of periphery, is also limited by commutation, because an increase in its value requires a corresponding increase in the cross-section of copper so as to keep the copper loss per inch of periphery unchanged. For a given temperature rise, therefore, the slot depth increases as the square of the value of q and commutation soon becomes unsatisfactory.

The value of ψ is limited by the leakage flux. If the pole pitch of a machine is increased, the armature ampère turns per pole, and therefore the length of the air-gap, increase in the same ratio, and the leakage flux between the pole tips will increase with respect to the flux crossing the gap unless the interpolar space is also increased. It is usual, therefore, to limit the pole arc to 0.7 times the pole pitch. If a greater value is used the leakage flux becomes excessive, while with a smaller value too large a percentage of the armature surface is inactive.

FIG. 12.



Values of the output constant.

Up to 1910 the increase in the output factor was due principally to improvements in brushes and to the accumulation of test data that allowed designers to work closer to the limit and gradually raise the value of q. The last increase over the values of 1910 has been due to the gradual introduction of interpoles.

With non-interpole generators it is usual to shift the brushes forward from the geometrical neutral so that the short-circuited coils are under the pole tips and in a reversing field. In the interpole generator, on the other hand, the pole tips are shifted backwards so as to influence the short-circuited coils, and series windings are placed around them to make the strength of the reversing field directly proportional to that of the current to be reversed. With commutation thus taken care of, it would seem that there could be no objection to the use of deep and narrow slots and to a large increase in the value of q and of the ratio tooth/slot, and yet it may be seen from Fig. 12 that since interpoles have come into general use the output factor has not increased much over twenty per cent.

FIG. 13.

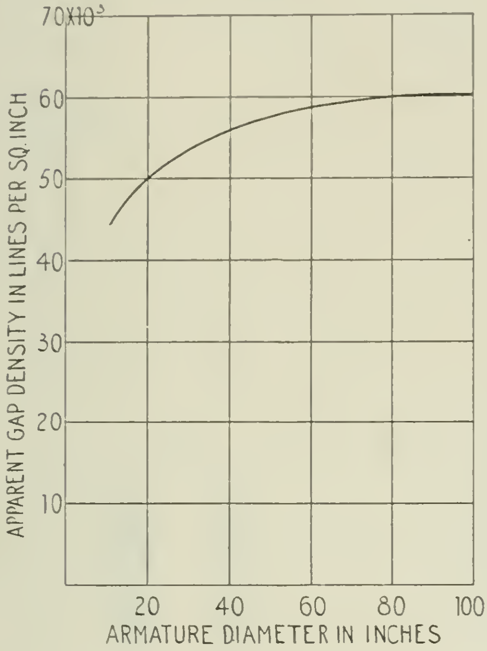


FIG. 14.

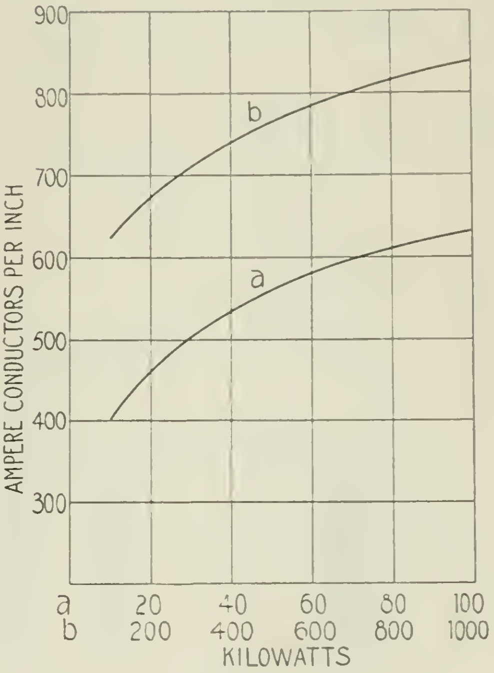


FIG. 13.—Average values of gap density used in non-interpole machines of 1910.

FIG. 14.—Average values of ampere conductors per inch of armature periphery used in non-interpole machines of 1910. Values 20 per cent. higher are often found in machines of 1917.

INTERPOLE AND COMPENSATED MACHINES.—Probably the best understanding of the interpole problem can be obtained by the working out of an actual example as follows:

Kilowatts	1,200
Volts	720
Ampères	1,670
Revolutions per minute	600
Poles	8

Slots per pole	14
Size of slot	0.54 inch x 1.5 inch
Conductors per slot	6
Size of conductor	0.12 inch x 0.55 inch
Type of winding	One turn per coil; multiple
Tooth/slot	1.33
a. Ampère conductors per inch of periphery	1,000
b. Circular mils per ampère	400
Ratio *a*/*b*	2.5
Peripheral velocity of armature	7,000 feet per minute
Commutator segments	336
Segments covered by the brush	3
Average volts per segment = 720/segments per pole	17.1
Pole enclosure	0.7
Embedded length of conductor	16.5 inches
Length of end connection	27 inches

The reactance voltage if the brush arc were exactly equal to the width of one commutator segment would be

$$RV_{av} = 4\ T^2 I_c R\, S(2\phi_s L_s + \phi_e L_e)\ 10^{-8}$$

where $\phi_s = \frac{2.54 \times 4\pi}{10s}\left[\frac{d}{1.5} + \frac{t}{4} + a + .73 \times s \times \log_{10}\left(1 + \frac{\pi(\gamma - b)}{2s}\right)\right]$

$= 5.9\ (.37 + .025 + .25 + .48) = 6.6$

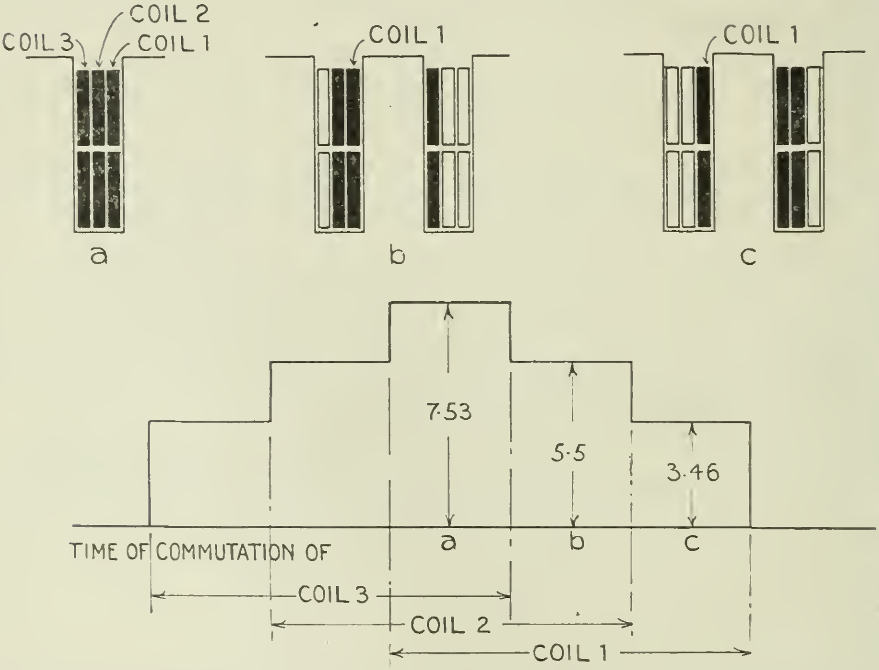
$\phi_e = 2.54 \times .46\left(\log_{10}\frac{27}{.4} - .2\right)$

$= 1.9$

and $RV_{av} = (2.4 \times 10^{-2})\ (2 \times 6.6 \times 16.5 + 1.9 \times 27)$

$= 6.1 + 1.43 = 7.53$ volts.

FIG. 15.



Stages in the commutation of a machine which has six conductors per slot, a full pitch winding and the brush width equal to the width of three commutator segments.

The brush, however, covers three segments, so that the flux linking each coil at the instant *a*, Fig. 15, will be three times as large as when only one segment is covered by the brush. The time of commutation, however, is also increased in the same ratio, so that at the instant *a* the reactance voltage of coil 1 is approximately

$$6.1 + 1.43 = 7.53 \text{ volts};$$

at instant *b* it is equal to

$$6.1 \times 2/3 + 1.43 = 5.5 \text{ volts};$$

and at instant *c* to

$$61 \times 1/3 + 1.43 = 3.46 \text{ volts}.$$

FIG. 16.

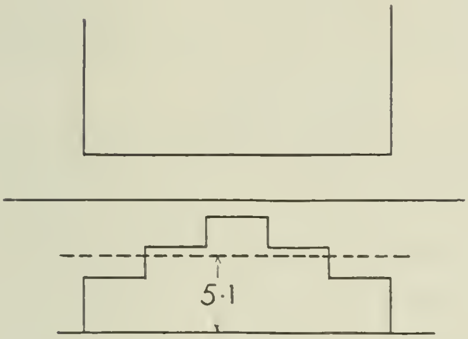


FIG. 17.

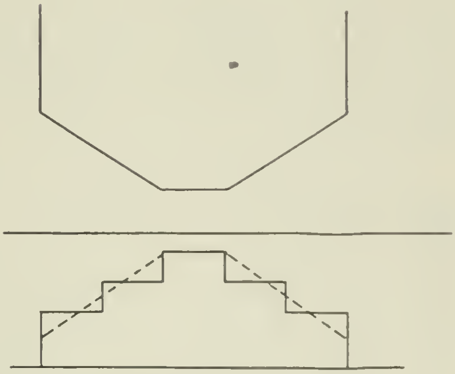


FIG. 16.—Commutation with a uniform air-gap under the interpole.
FIG. 17.—Improvement in commutation due to suitable shaping of the interpole tip.

If the air-gap under the interpole were uniform, as in Fig. 16, the voltage to be generated in each coil as it passed under the interpole would be 5.1 volts

and $5.1 = 2 \times L_i \times V_c \times B_g \times 10^{-8}$

where L_i = axial length of interpole = 15.5 inches.

V_c = peripheral velocity of armature in inches per second = 1420

so that

B_g = average interpole gap density = 11,500 lines per square inch.

Now, the ampère turns required to produce this flux density of 11,500 lines per square inch may be obtained from the formula

$$B_g = 3.2 \frac{\text{ampère turns}}{\text{effective air-gap in inches}}$$

And if the gap = 0.5 inch, then the ampère turns = 1800. Thus we have

Armature ampère turns per pole = 8,800
Interpole gap ampère turns = 1,800
Ampère turns for interpole = 10,600
= k (armature ampère turns per pole).

where k in this case is 1.2, and is seldom less than this value, so as to leave some working margin for adjustment of the interpole gap when the machine is installed.

A few years ago it was the practice to make the interpole ampère turns 40 per cent. greater than the armature ampère turns per pole, and then to adjust for sparkless commutation by means of a shunt across the interpole winding. For machines such as railway generators, where the load changed rapidly, an inductive shunt was used so as to make the interpole winding take its proper share of the current at all times.

In a machine where the reactance voltage differs from that generated by the interpoles by as high a value as $(7.53-5.1) = 2.43$ volts, an attempt would be made, by shaping the interpole tip as shown in Fig. 17, to generate a voltage which is more nearly opposed to the reactance voltage at every instant and which therefore varies as shown by the dotted curve. A short pitch winding also would probably be used, so that the upper and lower layers of conductors in a slot would not be undergoing commutation simultaneously, and the reactance voltage would thereby be reduced.[9]

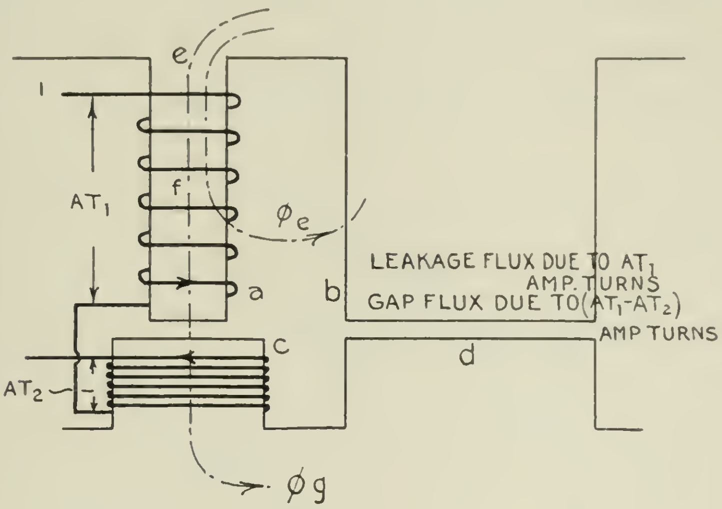
It is evident that in this particular machine, which is of rather high speed for the output, the reactance voltage has reached a value which cannot safely be exceeded, so that it would not be advisable to increase the slot depth in order to increase the value of q, the ampère conductors per inch of periphery. In case of slow-speed machines, on the other hand, the reactance voltage is low and interpoles are not really necessary. The value of q in such cases is limited more by heating than by commutation, because with the poor ventilation obtained in slow-speed units low current densities are required, and any large increase in the value of q over the values given in Fig. 14 would be accompanied by abnormally deep slots. The tendency, however, is towards higher speeds, now that the commutation limit has been raised by the use of interpoles.

---

[9] "Effect of Brush Width on Commutation," by Lewis, *Electrical Journal*, vol. xviii, August, 1916 (p. 376).

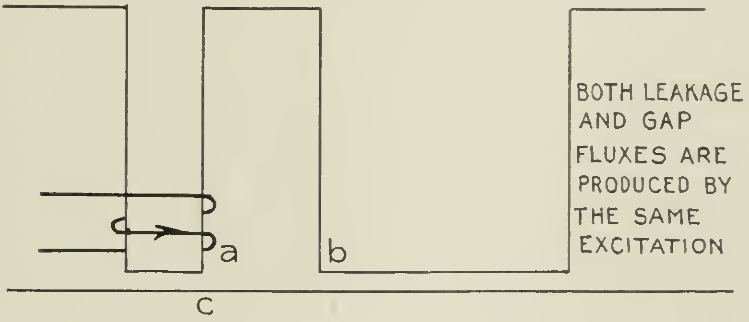
There is one limitation to be found in interpole machines which differs from anything we have in the non-interpole type.

FIG. 18.


e
1
AT$_1$
f
ϕ_e
LEAKAGE FLUX DUE TO AT$_1$ AMP. TURNS
GAP FLUX DUE TO (AT$_1$-AT$_2$) AMP TURNS
a
b
c
d
AT$_2$
ϕg

Magneto-motive forces as found in interpole machines.

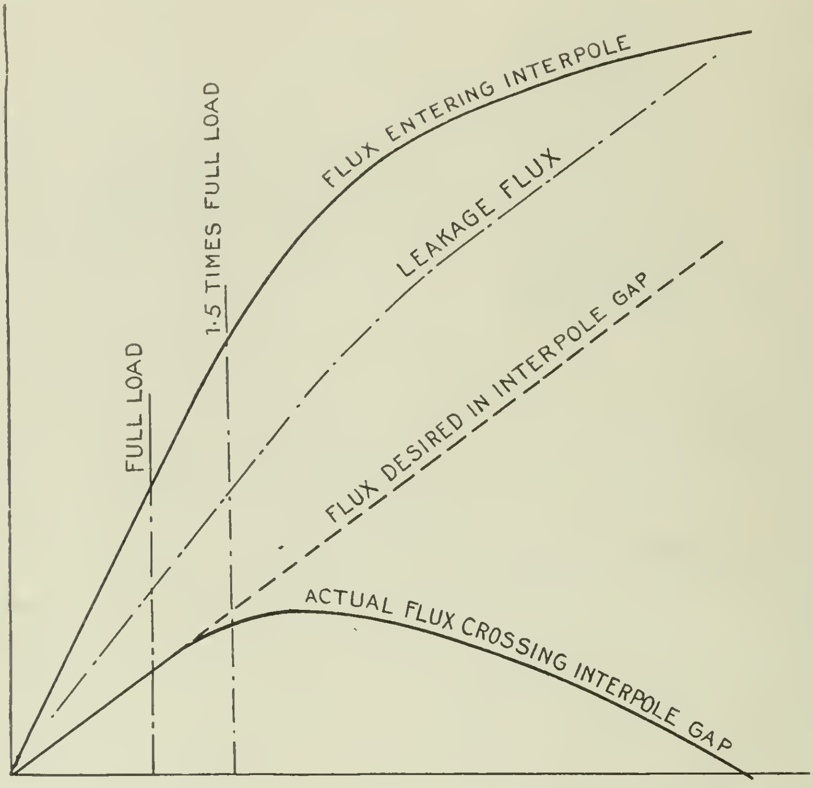
FIG. 19.


BOTH LEAKAGE AND GAP FLUXES ARE PRODUCED BY THE SAME EXCITATION
a
b
c

In compensated machines the only effective magneto-motive force that can cause interpole leakage is the small value due to the interpole excitation.

In Fig. 18, if AT_1 is 20 per cent. greater than AT_2, then the m.m.f. tending to send flux from a to b is five times as large as that tending to send flux from a to c, and, as the area of the leakage path ab is large compared with that of the main path ac, the leakage flux ϕ_e is large compared with the useful flux ϕ_g. This tends to cause saturation in the part ef of the flux path, even although the densities in the part cde of the path be low and, because of this saturation due to leakage flux, the useful flux is not directly proportional to the current.[10] Now these are exactly the conditions that exist in interpole machines, and the curves in Fig. 20 show how the magnetic fluxes vary with the interpole current in an actual machine.

FIG. 20.



Test curves showing the effect of interpole leakage on the value of the interpole gap flux.

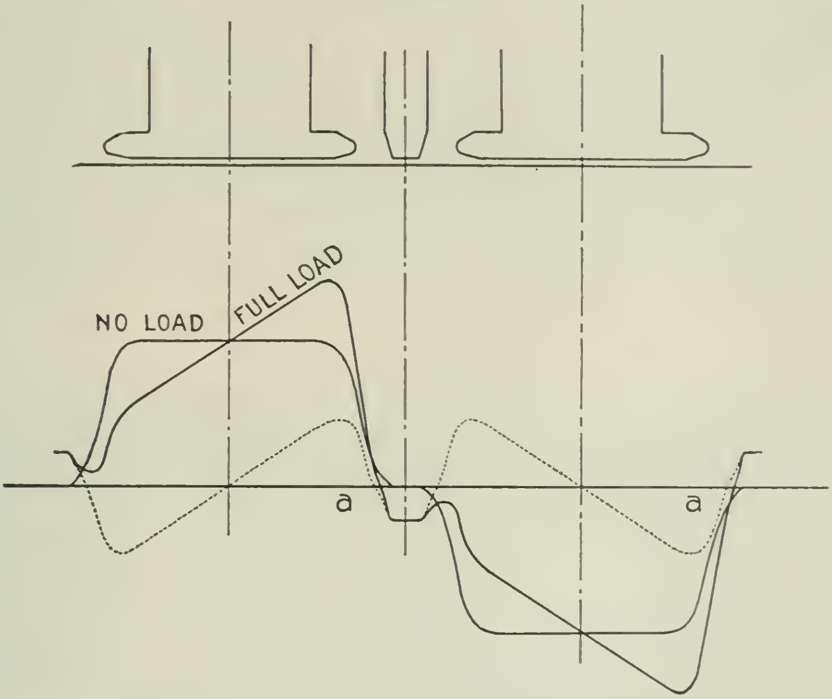
For good commutation over a wide range of load it is necessary that the field in the interpole gap increase directly with the armature current. If, for example, the reactance voltage at full load is exactly balanced by the voltage due to the interpole field, then, as shown in Fig. 20, only 90 per cent. of the reactance voltage is balanced at 50 per cent. overload and commutation is impaired. To keep the interpole leakage down to a value that will not cause trouble it is necessary to limit the ratio of the ampère turns on the interpole to the length *ab,* Fig. 18, and this means the setting a limit to the value of *q,* the ampère conductors per inch of periphery.

---

[10] "Commutating Poles," by Stokes, *Transactions of A. I. E. E.*, vol. xxxii, June, 1913 (p. 1540).

One other feature of the design on page 31 is of considerable importance. The average voltage between commutator segments has the high value of 17.1 volts, and if the flux distribution curve in the air-gap at full load is as shown in Fig. 21, then the voltage between the segments of a coil located at *a* is about 30 volts and there is a tendency for the machine to flash over, which tendency becomes greater with increase of load. It has been shown that arcing between the segments of large machines is liable to start at about 30 volts,[11] so that the machine will not carry any overload unless armature reaction is so compensated as to prevent distortion of the field. This result is accomplished, as shown in

Fig. 21.



Flux distribution in the air-gap of an interpole machine.

---

[11] "Physical Limitations in Direct-Current Commutating Machinery," Lamme, *Transactions of A. I. E. E.,* vol. xxxiv, September, 1915.

Fig. 22, by placing a winding on the pole face which has a number of ampère turns per pole equal and opposite to that of the armature winding. The interpole is still required to overcome the reactance voltage, but the number of ampère turns on the interpole need only be that required to produce the desired flux density, since the effect of armature reaction has been wiped out by the compensating winding. In the machine on page 31, for example, we found that

Armature ampère turns per pole = 8800
Interpole gap ampère turns = 1800
Ampère turns for the interpole = 10,600

When a compensating winding is placed on this machine, however, we have:

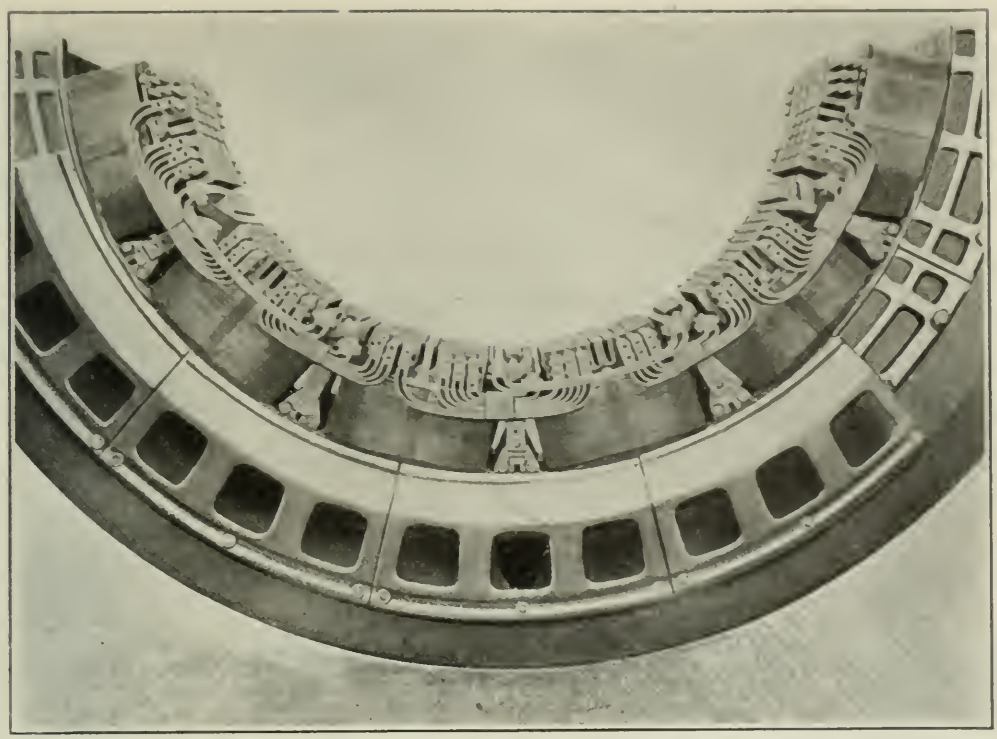
Armature ampère turns per pole = 8800
Compensating ampère turns per pole = 8800
Interpole gap ampère turns = 1800
Ampère turns for the interpole = 1800

Another great advantage of the compensated machine will now be apparent. In Fig. 19 the m.m.f. between *a* and *b* is equal to that across *ac* and not five times as large as in Fig. 18; the interpole leakage flux is therefore small, the interpole does not become saturated, and commutation is satisfactory over the wide range of load handled by such machines as rolling-mill motors and railway generators.

EFFECT OF SPEED ON OUTPUT.—The statement has been very generally made that the direct-current machine is essentially a slow-speed machine. The speeds, however, have gradually increased as interpole machines replaced those of the older type. Thus the 2750-kilowatt units of the Boston Elevated Company, installed in 1903, ran at 75 revolutions per minute, while the 3750-kilowatt units installed in Cleveland in 1911 had a speed of 180 revolutions per minute. In the case of motor-generator sets again, where there is no restriction to the speed except that the cost for a given output shall be a minimum, the development has been as follows:

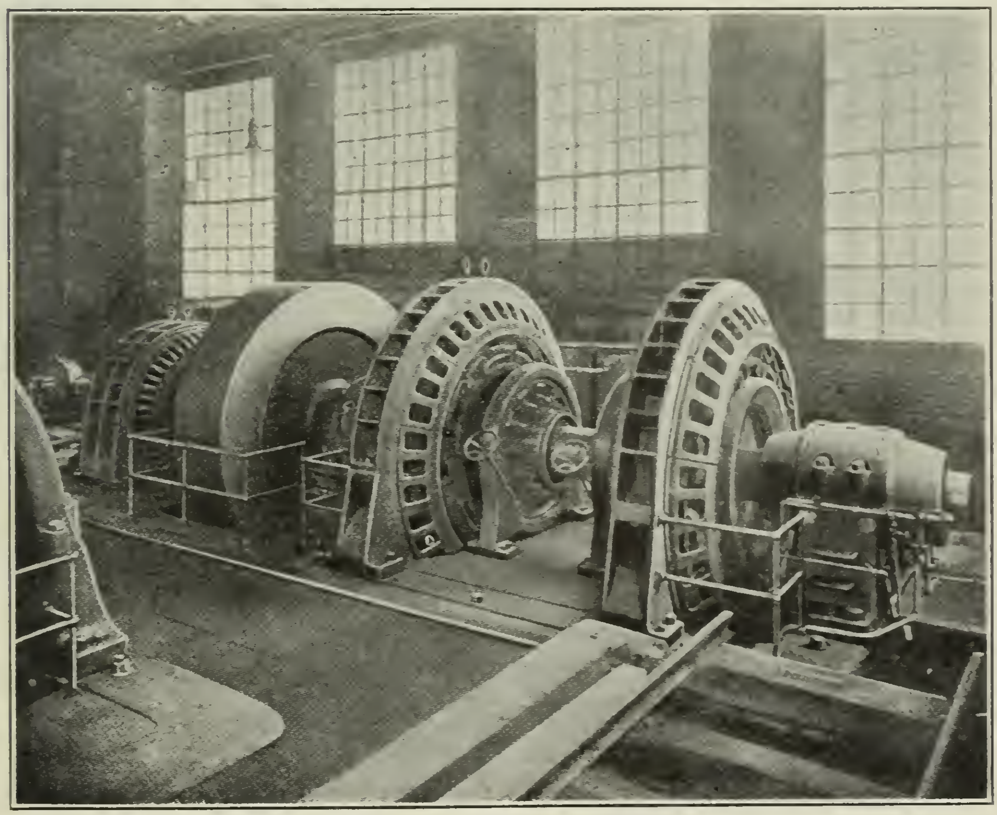
Date	Poles		Kilowatts	Volts	R.p.m.	Weight, pounds
1906	10	interpole	1000	600	514	33,000
1910	8	interpole	1000	600	750	24,000
1916	6	interpole and compensated	1000	600	900	19,000

FIG. 22.



Part of a flywheel motor generator set under construction, showing interpole and compensating windings.

FIG. 22A.



Flywheel motor generator set of which the above machine is a part. This set was installed by the Algoma Steel Company to feed two reversing rolling mill motors.

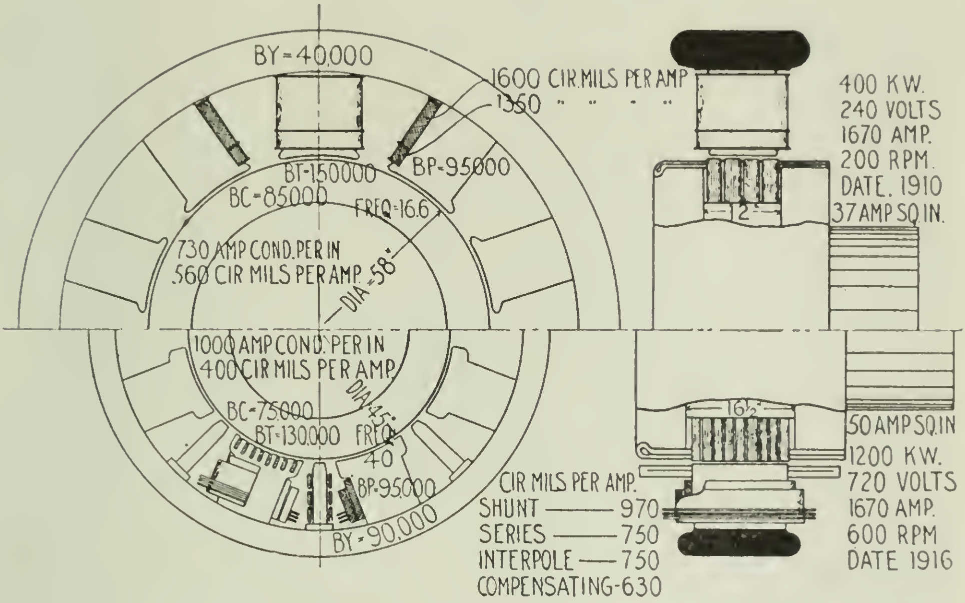
These speeds, however, do not begin to compare with those found in alternator practice; turbo machines of 6500 kv.a. capacity now run at 3600 revolutions per minute. To find wherein the direct-current machine is limited, let us take a good type of non-interpole machine, gradually raise the speed, and see what limits are encountered. Column 1, Table II, gives data on such a machine. If the speed is doubled, so also are the voltage and the output; also the reactance voltage has passed a safe value and interpoles become necessary. At three times normal speed the average voltage between segments has become so large that compensating windings are required, nor can the speed be increased much further without danger of flashover, even although the armature is compensated.

TABLE II.

	1	2	3	4
Kilowatts	400	800	1200	1200
Volts	240	480	720	720
Ampères	1670	1670	1670	1670
Revolutions per minute	200	400	600	600
Slots per pole	20 (.43″x 1.6″)	....	....	14 (.54″x 1.5″)
Conductors per slot	4 (.14″x .85″)	....	....	6 (.12″x .55″)
Tooth/slot	1.11	Smaller than necessary		1.33
B_t lines/square inches	150000	....	Too high	130000
B_c lines/square inches	83000	....	Too high	75000
Frequency	16.6	33.3	50	50
Armature A. T. per pole	6700	....	....	8800
Ampère turns (gap and tooth)	8280	Larger than necessary		6000
Ratio	1.23	....	....	0.68
Gap clearance	0.3	Larger than necessary		....
Reactance voltage	1.6	3.2 need interpoles	4.8 need interpoles	7.53
Average volts per segment	6.0	12.0	18.0 need compensating wind.	17.2
Peripheral velocity, armature	3040	6080	9120	6600
commutator	1830	3660	5490	4200
Ampère conductors per inch (armature)	730	Smaller than necessary		1000
Ampère square inch, armature conductor	2250	Smaller than necessary		3200
Ampère square inch, brush contact	37	Smaller than necessary		50
Volts drop per pair brushes	2.5	Larger than necessary		2.0

It is true that the machine would be somewhat modified because of the high speed; thus the teeth would be wider to reduce the flux density, also the current density would be increased because of the better ventilation, but these facts do not materially change our conclusions. The actual design, given in column 4, is drawn for comparison in Fig. 23 alongside of the original 200-r.p.m. design, and shows very clearly complications that have been made necessary by high speeds. This complication may also be seen by a comparison between Figs. 24 and 25.

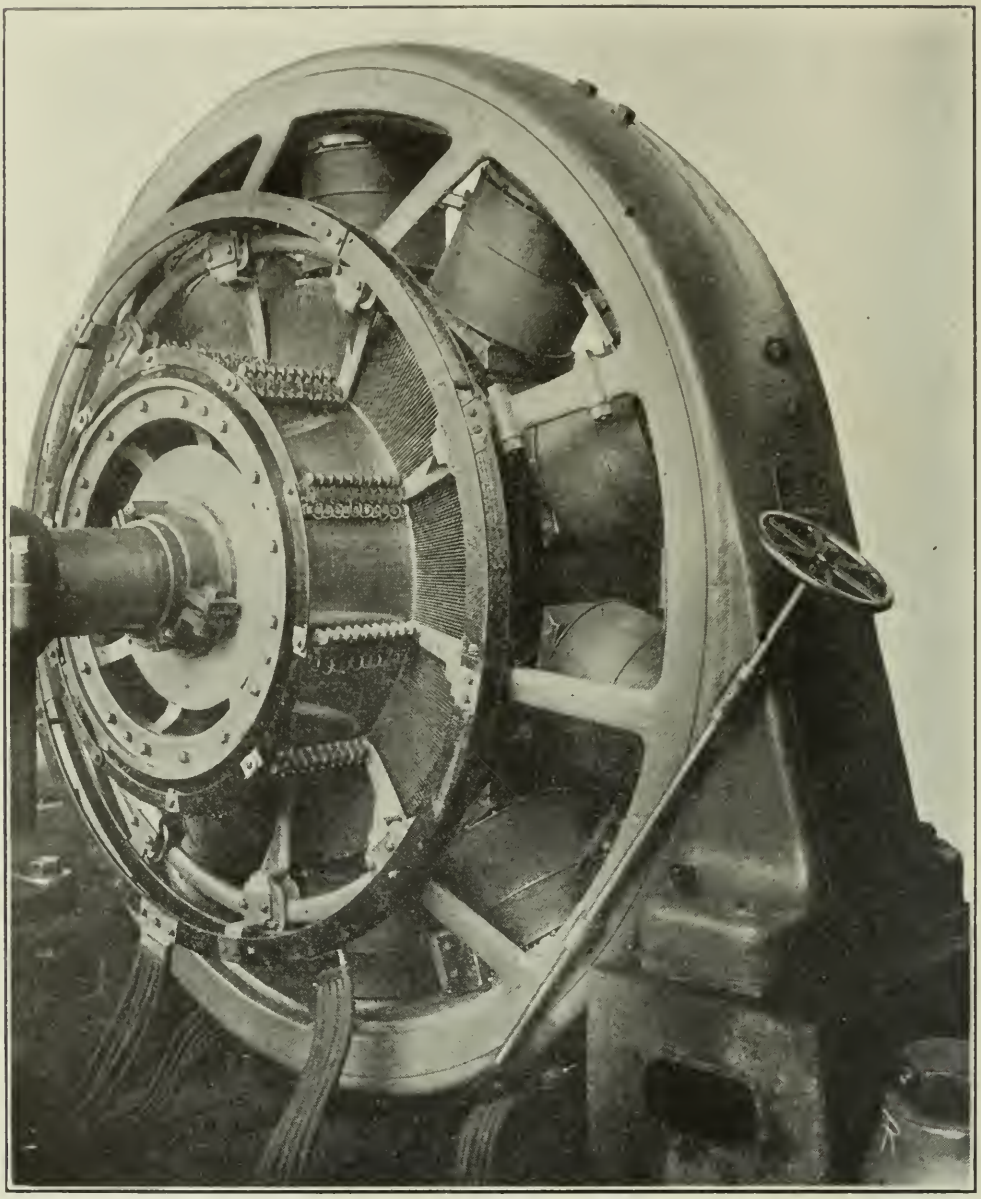
Fig. 23.



Comparison between a slow-speed and a high-speed machine with the same output per revolution.

It would appear, then, that there is a limit to the capacity of the generator that can be built for a certain speed. If, for example, the revolutions per minute have been fixed, the maximum diameter that may safely be used is limited by the peripheral velocity. With the diameter thus fixed, the output of the machine is limited by the length of the armature core. As this element is increased in value the reactance voltage also increases, and finally interpoles become necessary for successful commutation. The core length may now be further increased, but a second limit is soon reached at which the voltage between two adjacent commutator segments becomes of such a value that the machine is liable to flash over. Let us therefore fix limits to the peripheral velocity of the armature, to the reactance voltage, and to the voltage be-

FIG. 24.



Engine type of generator without interpoles, date 1904.

tween adjacent commutator segments, and see what sort of an output equation can be built up that will embrace these quantities.

(*a*) *Non-interpole machines:*

$$\text{Watts} = \frac{\mathrm{B}g\Psi q}{6.08 \times 10^8} (D^2L)\text{rpm.} \quad \left(\text{see page 29}\right)$$

and $RV = 4T^2I_c \frac{\text{rpm}}{60} S(2 \times 10 \times L_s + 2L_e)10^{-8}$ for a full pitch winding (see page 25).

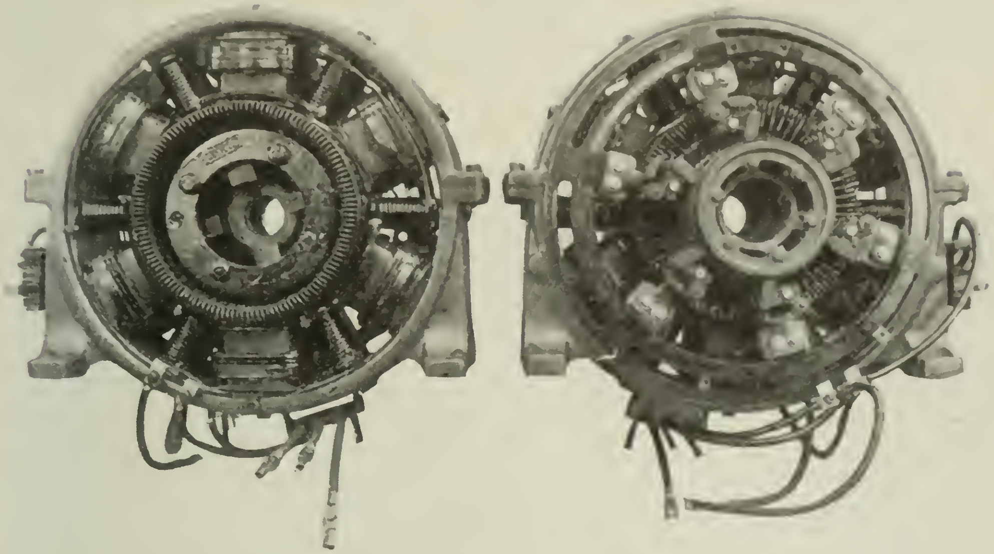
$= SI_cL \times \text{rpm} \times 10^{-8}$ approximately for a *short pitch* multiple winding with one turn per coil.

$$= \frac{\pi Dq}{2} \times L \times \text{rpm} \times 10^{-8}$$

therefore watts $= \dfrac{B_g \Psi\ (RV)}{6.08} \times \dfrac{2}{\pi} \times p$

$$= 0.4\ B_g\ (RV)\ V_a\ \text{rpm}.$$

FIG. 25.



Engine type of generator with interpoles, date 1915.

If we take B_g = 60,000 lines per square inch (see Fig. 13).
Ψ = 0.7 (see Fig. 9).
RV = 2.5 (see page 25).
V_a = peripheral velocity of armature = 9000 feet per minute.

then the maximum output in kilowatts 380.000 r.p.m. which is the equation to the curve for non-interpole machines given in Fig. 26.

(*b*) *Interpole machines*

In this case the output is limited by the voltage between adjacent commutator segments and

watts = volts per conductor × current per conductor
number of conductors

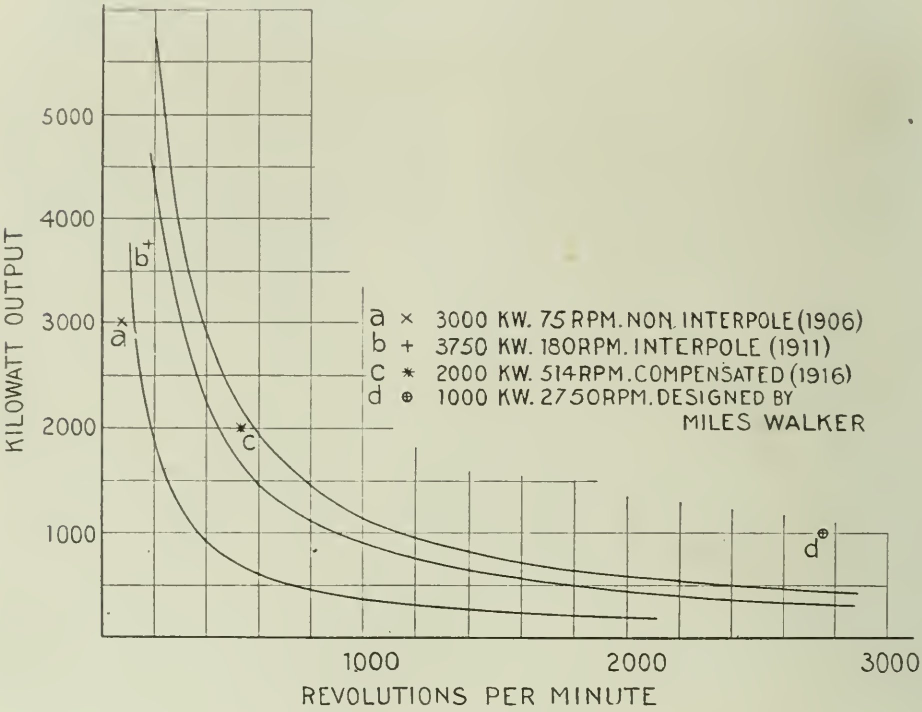
$$= \frac{E_s}{2} \times \pi Dq \text{ for a one turn multiple winding}$$

$$= \frac{E_s}{2} \times \frac{12\ V_a}{\text{rpm}} \times q$$

The voltage E_s between adjacent commutator segments must not be large enough to maintain any arc that may be started between the segments. Small machines have been operated successfully with a maximum value of 60 volts between segments, but it has been found that in the case of machines of large output, where the resistance of that part of the winding between two segments is necessarily very low, it is not safe to operate with a maximum in excess of 30 volts between segments.

In Fig. 21 the no-load and also the full-load flux distribution curves are shown. From such curves it will be found that the average voltage between segments is 0.72 times the maximum when the machine is operating at no load, and is only 0.55 times the maximum value when the field is distorted by the full-load current in the armature; this latter figure is for an average interpole machine in which the exciting ampère turns per pole for gap and teeth is about 0.8 times the armature ampère turns per pole at full load. If, then, the maximum voltage between segments is limited to 30 volts, the average voltage between segments should not exceed 0.55 x 30 = 16.5 volts, or even 15 volts if the machine is liable to be overloaded. If, however, a compensating winding is placed on the pole face, values as high as 0.72 x 30 = 21.5 volts may be used.

FIG. 26.



Maximum output of direct-current generators.

If we take

$V_a = 9000$ feet per minute;

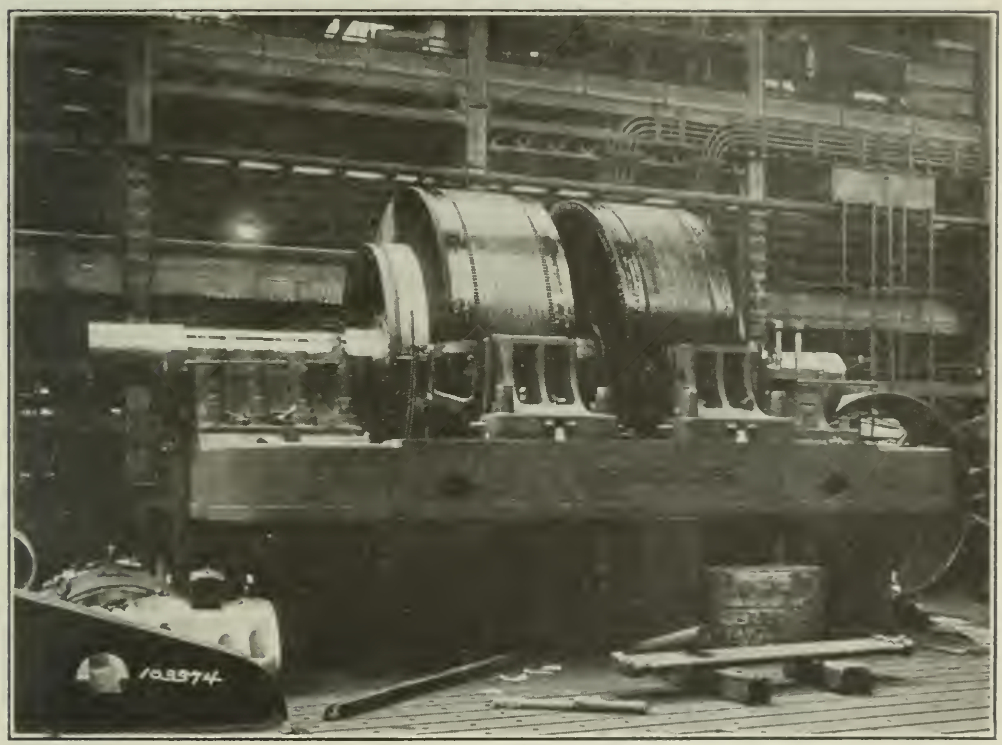
$q = 1100$ ampère conductors per inch (see Fig. 14);

$E_s = 15$ for interpole machines;

$= 20$ for compensated machines;

then the maximum output in kilowatts $= 900{,}000/\text{rpm.}$ (interpole) or $1{,}200{,}000/\text{rpm.}$ (compensated); and these are the equations to the curves for interpole and for compensated machines given in Fig. 26.

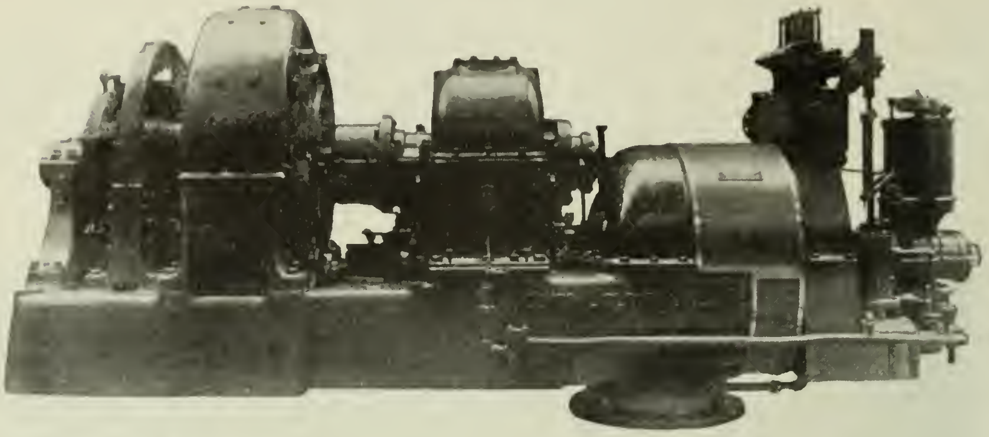
FIG. 27.



15,000-horsepower reversing rolling-mill motor of the two machine-type. Speed 0 to 120 r.p.m.

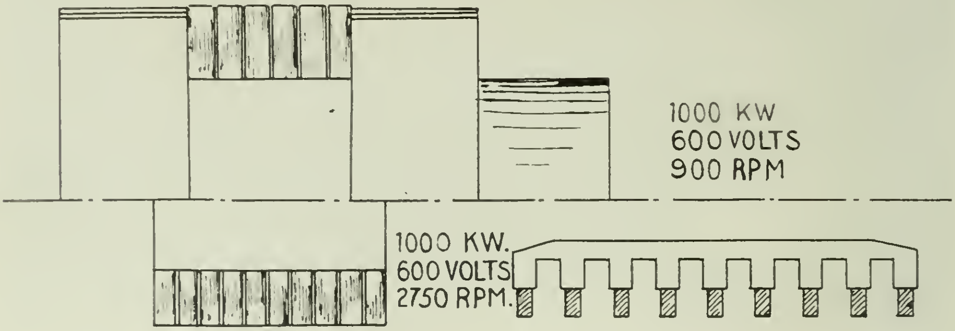
It must not be supposed that the values given by the three curves in Fig. 26 have not been exceeded. There are a number of non-interpole machines of 3000 kilowatts at 375 revolutions per minute in operation at the Illinois Steel Company, South Chicago, and yet the curves indicate that 125 revolutions per minute is about the limit in speed for machines of this output. They were built, however, with one segment per conductor instead of one segment per coil so as to reduce the reactance voltage to half value, this result being obtained by the use of connectors brought to the commutator from the back of the armature winding. Then the Westinghouse Company has built a number of reversing mill motors rated at 15,000 horsepower at 120 revolutions per minute. These have been made possible by the adoption of a two-unit type, as shown in Fig. 27. Again, Miles Walker [12] has given data on a 1000-kilowatt turbine-driven machine which operates at 2750 revolutions per minute. This machine also has one segment per conductor, and it has a compensating winding. The constants of interest are

FIG. 28.



500-kilowatt geared turbo-generator with a speed reduction of 5000/900 r.p.m.

FIG. 29.



Comparison between a geared and a direct-connected turbo-generator of the same output.

$E_s = 17$ volts between segments.
$q = 800$ ampère conductors per inch.
$V_a = 17{,}300$ feet per minute.

The machine, therefore, will operate successfully. It would appear, however, that British manufacturers have something to teach us about the construction of high-speed commutators, because the commutator for this particular machine has nine shrink rings and a rubbing velocity of 10,000 feet per minute. Some development work on similar machines has been done in this country, but there has been little demand for the machine in large sizes, and it has been almost entirely superseded by geared units, such as that shown in Fig. 28, where the generator and the turbine each runs at the speed for which it is best suited. The essential differences between the two types of machine are shown in Fig. 29. The important design constants are:

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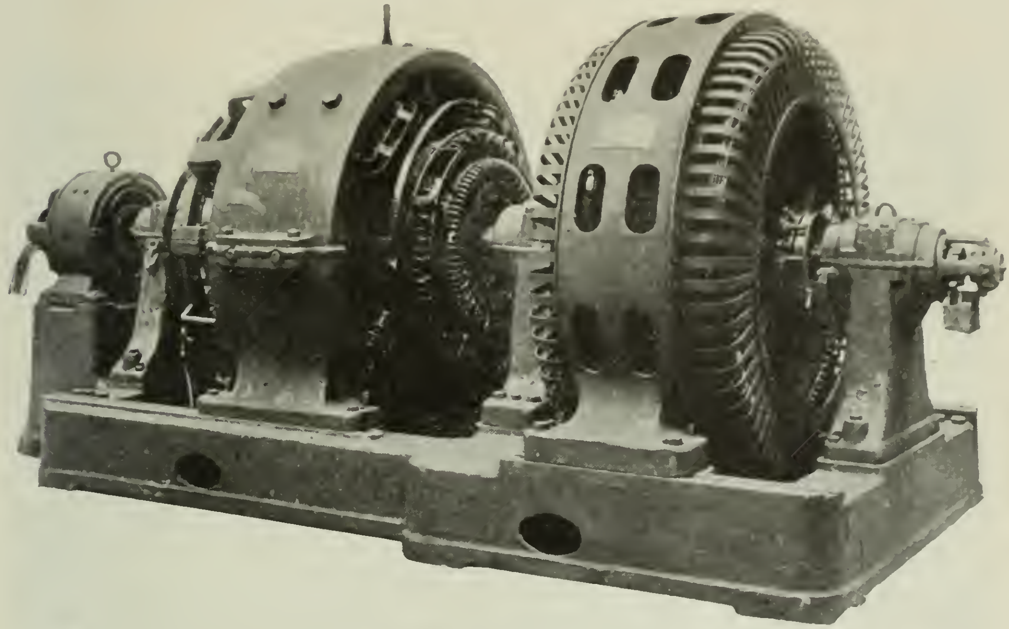
[12] "Design and Specification of Dynamo Electric Machinery."

Fig. 30.

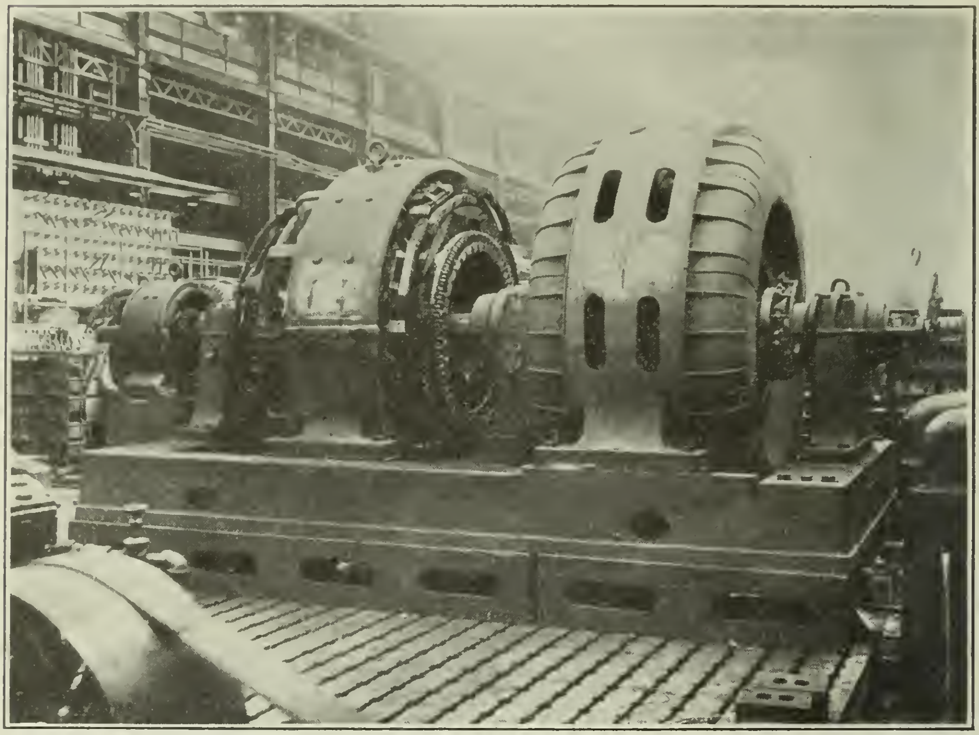


Motor generator set with compensated interpole direct-current generator. The construction of the compensating winding is of interest because it is of a double-layer, barrel type similar to that on the stator of an induction motor.

Kilowatts	1000	1000
Volts	600	600
Revolutions per minute	2750	900
Poles	4	6
Armature diameter in inches	24	36
Core length in inches	21	15
Maximum tooth density in lines per square inch	94,000	135,000
Core density in lines per square inch	68,000	85,000
Frequency in cycles per second	92	45
Armature surface velocity in feet per minute	17,300	8500
Commutator rubbing velocity in feet per minute	10,000	5000
Ampère conductors per inch	800	880
Circular mils per ampère	550	450
Average volts per segment	17	20

Interpoles and compensating windings had been suggested as early as 1886, but we find that as late as 1904 S. P. Thompson wrote as follows:[13] "It is an open question whether the employment of any of the more elaborate devices can come commercially into use except perhaps for machines of moderate output. An examination of the largest machines of the present day about which there can be no question as to the successful operation invariably shows that the heating limit is reached before the point at which sparking occurs." The development that has taken place during the last thirteen years can perhaps be appreciated when we find ourselves compelled to state that "There is no question but that without interpoles and compensating windings it would be impossible to build machines to carry the overloads, to operate at the high speeds and through the wide ranges of speed that are expected to-day by the operating engineer."

FIG. 31



Motor generator set with compensated interpole direct-current generator. The compensating winding is constructed similar to the well-known chain winding in alternators, and should be compared with the construction shown in Fig. 30.

(*To be continued.*)

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[13] "Dynamo Electric Machinery," vol. i, 1904 edition, p. 272.

RECLAIMING THE EVERGLADES OF FLORIDA.*

BY

ISHAM RANDOLPH, D.Eng.,

Member of the Institute

Ponce de Leon discovered Florida, March 27, 1512. I discovered it in 1913; not that I had not previously seen on the map a flat, misshapen projection fending the Gulf of Mexico from the broad Atlantic. I had heard of St. Augustine and even of Tallahassee, but, apart from this casual hearing and seeing, the land of flowers was a *terra incognita* to me.

I was invited by Governor Park Tramel to come to Tallahassee to meet him and his fellow-members, Trustees of the Internal Improvement Fund of the State of Florida, to counsel with them about the drainage of the Everglades.

The name applied to that broad expanse of semi-aqueous land gave me no conception of its characteristics; those were to be revealed later.

When leaving Chicago, April 24, 1913, I equipped myself with the best map I could procure of the State with whose development I was so soon to be associated, and thereon was indicated a lake of considerable magnitude and named Okeechobee; a name conferred by the first inhabitants of a land in the State of Nature, but not then in the United States. Below this lake stretched an expanse almost coequal with the area of the lower peninsula, and on this was printed "Everglades." There were lines leading from the lake in a southeasterly direction, and these were labelled "canals," and they ended in natural channels leading to the Atlantic. They were sixty or seventy miles long, whereas the lake was only 25 miles away from an estuary.

When I met the Floridian powers that then were, on April 28, after a few preliminaries, I said to them that the whole subject was new to me and that, therefore, I might be "talking through my hat," but that, with the superficial knowledge I then had, I was led to believe that what was needed was a canal leading from the lake to the sea by the shortest possible route; and that locks should be put in the existing canals to prevent the lake water from flowing out over the Everglades.

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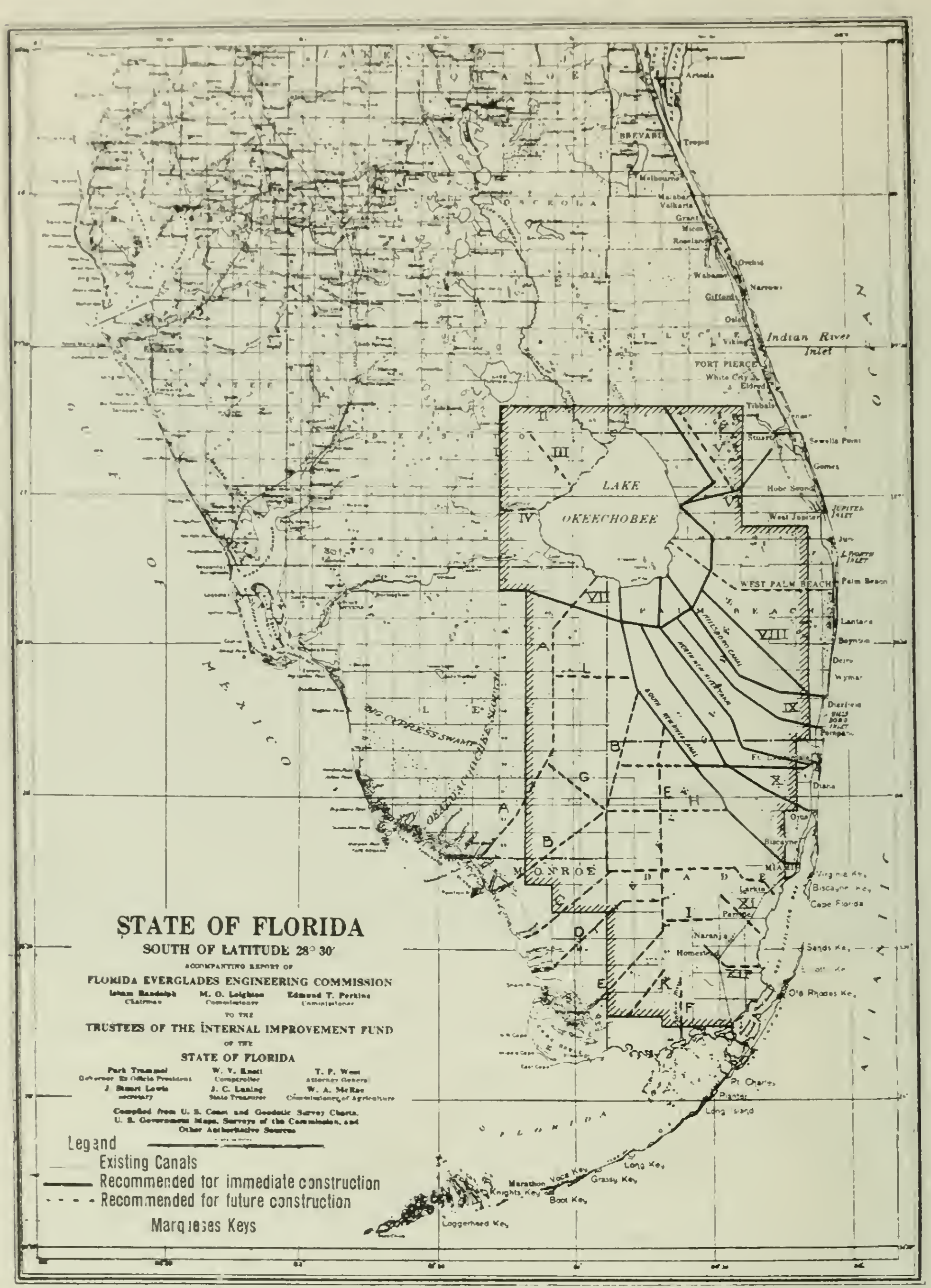
* Presented at the Stated Meeting of the Institute, held Wednesday, February 21, 1917.


STATE OF FLORIDA
SOUTH OF LATITUDE 28° 30′
ACCOMPANYING REPORT OF
FLORIDA EVERGLADES ENGINEERING COMMISSION
Isham Randolph Chairman
M. O. Leighton Commissioner
Edmund T. Perkins Commissioner
TO THE
TRUSTEES OF THE INTERNAL IMPROVEMENT FUND
OF THE
STATE OF FLORIDA
Park Trammel Governor Ex Officio President
W. V. Knott Comptroller
T. F. West Attorney General
J. Stuart Lewis Secretary
J. C. Luning State Treasurer
W. A. McRae Commissioner of Agriculture
Compiled from U. S. Coast and Geodetic Survey Charts, U. S. Government Maps, Surveys of the Commission, and Other Authoritative Sources
Legend
Existing Canals
Recommended for immediate construction
Recommended for future construction
Marquesas Keys
LAKE OKEECHOBEE
Indian River Inlet
FORT PIERCE
WEST PALM BEACH
MIAMI
BIG CYPRESS SWAMP
MONROE
Melbourne
Stuart
Jupiter Inlet
Palm Beach
Lantana
Boynton
Delray
Pompano
Biscayne
Cape Florida
Homestead
Old Rhodes Key
Long Island
Long Key
Grassy Key
Marathon
Knights Key
Boot Key
Loggerhead Key
I II III IV V VI VII VIII IX X XI XII
A B C D E F G H

Senate Doc. No. 379 : 63d Cong., 3d Sess.

Map of the Everglades.

To cut a long story short, I was engaged to organize a commission to report upon the problem and empowered to cause to be made the necessary surveys and other investigations essential to a proper knowledge of the facts.

I associated with me two very able engineers. Mr. Marshall O. Leighton, who was for many years officially and most responsibly connected with the U. S. Geological Survey and was, and is, a recognized authority on hydrology and its collateral subjects. The other selection was Mr. Edmund T. Perkins, who had been responsibly connected with the engineering branch of the Department of the Interior. I assigned the hydrometric and meteorologic branch of the investigations to Mr. Leighton and the surveys to Mr. Perkins.

You may ask what I did; well, among other things, I, like the owl, did a "heap o' thinking."

We organized several survey parties and put them into the field, and it was a source of profound thankfulness that I did not have to follow them over the lines they run, for the hardships and discomforts which they endured were very great.

I was first to see the Everglades from the deck of the motor yacht *Pearl*, chartered for our use. On May 7 we passed through New River and into North New River Canal, headed for Lake Okeechobee, and it was not long after we entered that canal that my preconceived notions of the Everglades evaporated like morning mists. There was no growth of cypress and juniper, no tangle of vines, no contracted view, but a broad expanse of water-logged land over which the eye searched in vain for a landmark, a distinguishing feature. There were no trees, no bushes, no mounds, nothing to steer towards nor to back sight upon. Just flatness grown up with saw grass: saw grass sometimes eight or nine feet high. Saw grass needs an introduction, a definition of its qualities. It is a broad-bladed grass, very stiff, and each edge of the blade is serrated like the teeth of a hack-saw, and its cutting qualities are almost as pronounced as those of its steel prototype. When an unfortunate has to forge his way through this growth, it is only a question of time, and not a long time at that, before his bootlegs or his leather or canvas leggings are scarified and torn away. I said there was nothing to steer by, but the navigator of a canal so narrow that turning his boat in it is a task of some difficulty has little need of compass or range target; his liquid path is narrow, if not always straight, and all he has to do is to shun the banks on either side.

You will realize the vastness of this Everglade expanse when told that it is equal in square miles to the combined area of Connecticut and Rhode Island.

The only relief to the monotony of such a voyage as we were taking was afforded by the abundant and beautiful bird life, ducks, herons, cranes, limpkins, and other aquatic fowl—met so casually that their family names, if ever heard, have been forgotten—were a constant delight to the eye. Then, too, there were the alligators, little and big, and the snakes and other reptile life.

On a later voyage, made pleasant for us by the presence of our wives, they, the ladies, began counting alligators, but when they reached five score they tired of that census.

Taking a "Glade boat" to the Glades.

On the morning of May 8 we passed into Lake Okeechobee, the liquid heart of Florida, and on occasion that heart palpitates vigorously, as I was to realize to my discomfort at a later date when I was out on it in a storm. At the time of our first visit this lake had never been surveyed, and one of our duties was to determine its form and area. By an arrangement, which Mr. Leighton was able to perfect, this lake survey was made for us by Mr. E. P. Davis, Topographer of the U. S. Geological Survey. This survey was at our expense, but it is sponsored by the U. S. Geological Survey. The greatest width of the lake is, north and

south, 37 miles, and east and west, 31 miles; its area at elevation 19 above sea level is 725 square miles—which makes it the largest body of fresh water within the confines of any single state in the Union. It is a beautiful sheet of water, abounding with fish. So abundant are the finny tribes that the catch is an industry of great importance and its earnings run into six figures, and I am not sure that they do not call for seven. This catch was formerly shipped *via* the Caloosahatchie to Fort Myers and by the North New River Canal to Fort Lauderdale for shipment by rail to northern markets. But on the 6th of January, 1915, the track of the Florida East Coast Railway reached the north side of the lake and immediately a town sprang up, with the fishing industry as its inspiration. I was there early in November of that year and it then had 1100 inhabitants, a bank, electric light and ice plants, and other modern comforts and conveniences. Of course, the Florida East Coast Railway now takes all of "the catch" in its refrigerator cars and speeds it to northern markets. The harbor of this new town is on the Onoshohatchie Creek or River, which is a deep, crooked, and very picturesque stream. But the new town is on the north side of Lake Okeechobee, and,
River, which is a deep, crooked, and very picturesque stream.
ing from the lake southward to the Gulf; not bounded, however, by the Atlantic on the east and the Gulf of Mexico on the west, for there is on each side an inconsiderable uplift or ridge, and the Everglades fill the trough between these ridges. This uplift along the Atlantic coast is only a few miles wide, but much wider on the Gulf side.

What one sees of the Everglades is, as heretofore described, a vast expanse of saw-grass-covered, waterlogged soil. What one does not see is the solid substratum upon which this superimposed mass rests, and my ignorant preconceptions were first startled, then dissipated when I learned that the substratum is rock: rock whose general surface is level, but not smooth; it is full of pot-holes and minor indentations. How did this solid foundation for the peninsula come to be there? I do not know, but I accept with faith, not to be shaken until better proofs are forthcoming, the explanation given by Prof. Louis Agassiz in a report to the Superintendent of the Coast Survey, on examination of Florida reefs, keys, and coast, dated August, 1851. This report is "H. Doc. 26," Appendix No. 10. I quote the introductory remarks:

"To form a correct idea of the Florida reefs, it is of paramount importance to keep in mind the topographical features of the whole country. The peninsula of Florida projects between the Gulf of Mexico and the Atlantic, from the 30th degree of northern latitude nearly to the 24th, as a broad, flat, low promontory, which has generally been considered a continuation of the lowlands of the Southern States. But, as we shall see hereafter, this is not the case, or, at least, not with respect to the southern extremity of the peninsula, which consists of the same formations as the reef itself. Again, in a physical point of view, Florida is not limited to those tracts of land, forming the peninsula, which rise above the level of the sea, for the extensive shoals along its southern extremity, between the mainland and the keys and reefs, as well as those extending to the west as far as the Tortugas, whence they stretch along the western coast, in fact belong to it, and are intimately connected with it, by their physical character. There is a similar tract of flats along the eastern shore, but it is not so extensive as on the southern and western shores, nor does it partake as largely of the peculiar character of the peninsula, being chiefly formed of the alluvial sand, drifted ashore by the waters of the Atlantic."

Hill's party *en route* for Lake Okeechobee.

Agassiz credits the coral insect with this vast work of foundation building, as is shown by a further quotation:

"The reefs of Florida, as they have been described in the foregoing sketch of the topography of that state, and, indeed, the separate parts of each of these reefs, in their extensive range from northeast to southwest, present such varieties as will afford, when judiciously combined, a complete history of the whole process of their formation.

"Here we have groups of living corals, beginning to expand at considerable depth, and forming isolated, disconnected patches—the first rudiments, as it were, of an extensive new reef. There we have a continuous range of similar corals in unbroken continuity for miles, or even hundreds of miles, rising at unequal heights nearly to the surface.

"Here and there a few heads or large patches, or even extensive flats of corals, reach the level of low-water mark, and may occasionally be seen above the surface of the waters, when the sea is more agitated than by the simple action of the tides. In other places coral sands or loose fragments of corals, larger or smaller boulders, detached from lower parts of the living reef, are thrown upon its dying summits, and thus form the first accumulation of solid materials, rising permanently above low-water mark; collected sometimes in such quantities and at such heights as to remain dry, stretching their naked heads above high water.

"In other places these accumulations of loose, dead materials have entirely covered the once living corals, as far as the eye can reach into the depth of the ocean; no sign of life is left, except, perhaps, here and there an isolated bunch of some of those species of corals which naturally grow scattered, or of those other organisms which congregate around or upon coral reefs; but the increase of the reef by the natural growth of the reef-building corals is at an end. Again, in other places, by the further accumulation of such loose materials, and the peculiar mode of aggregation which results from the action of the sea upon them, and which will be more fully explained hereafter, extensive islands are formed, ranging in the direction of the mainland, which supports them. Elsewhere we may find the whole extent of the reef thus covered, which, after a still more protracted accumulation, perhaps becomes united with some continental shore.

"Now it must be obvious that, from a comparison of so many separate stages of the growth of a coral reef, a correct insight may be obtained into the process of its formation; and, indeed, in thus alluding to the different localities which came under our own observation, we have already given a general history of its progress, which we now proceed to illustrate more in detail.

" We would, however, first remark that the extraordinary varieties which exist in the natural condition of different parts of the same reef, or of different reefs, when compared with each other, fully explain the discrepancies between the reports which have been obtained, respecting the reefs of Florida, prior to our investigations.

" It had been stated that the reefs consisted solely of living corals; and, indeed, this report is true of the outer reef, which is called by all the inhabitants of Florida ' the reef ' *par excellence*, and is unfounded only with regard to those few islands which rise above the surface of the sea at Sand Key and the Sambos. Others, who had noticed only the larger accumulations of coral fragments which occur on the shores of some of the islands forming part of the Florida reef, had reported the islands to be formed of coral rocks; while some who had, perhaps, observed the extensive excavations made around Key West have told us only of the existence of oolitic and compact rocks, almost destitute of corals or other remains of animal life; and from still other localities comes the opinion that the rocks consist of nothing but more or less disintegrated shells, cemented together.

" Such are different species of Arca, the date-fish among the Mollusca, and many worms, especially Serpula among articulates, the agency of which in the formation of the keys will be described hereafter. All these animals and plants contribute, more or less, to augment the mass of solid materials which is accumulating upon the reef, and increase its size. Not only are the hard parts of shells, echinoderms, worms, or their broken fragments, heaped among the detritus of the corals, but occasionally even the bones of fishes and turtles, which are very numerous along the reef, may be found in the coral formations.

" The decaying soft parts of all these animals undoubtedly have their influence upon the chemical process, by which the limestone particles of their solid frame are cemented together, in the formation of compact rocks. Upon this point we may expect further information from Professor Horsford, who is now submitting to chemical analysis all the variety of rocks and the solid stems of the different corals obtained in Florida. Respecting the relations of the solid and soft parts of the living coral and their mode of growth, we would refer to a paper of ours now in press, to appear in the next volume of the 'Smithsonian Contributions to Knowledge.'"

Well, we know the rock is there, and the scientist quoted tells us how it came there.

It is overlaid with soil, the depth of which at Lake Okeechobee is from 14 to 20 feet, and this depth diminishes with the distance southward from the lake until at last the rock surface is visible and practically bare of soil.

"Flat Woods."

This statement would lead the hearer to conclude that a barren region had been reached, but, far from it, the rock is so porous that roots penetrate it and find elements to support arboreal life. Some of the best-looking orange groves in Florida flourish in this rock land.

A pot-hole is made by the use of dynamite or other method of excavation. The stone removed is pounded up, mixed with any available soil placed back in the hole it came from, the tree set in the spot thus prepared, and there it grows, thrives, and bears luscious fruit.

Mr. Kirk Monroe, author of many boys' books, said to me, "We farm here with pick and crowbar."

To get back to the work of our commission.

We put several parties in the field, and it would be interesting to follow the fortunes of each of these units, but to do so would far exceed the time limit which should be fixed for one evening's talk. So I will tell of the experiences of one party only—that in charge of Mr. George B. Hills. This survey was intended to develop a canal route from Lake Okeechobee through lowlands which would involve a minimum of excavation, and it followed the depression known as Loxahatchie slough. For a little while wagons were available for transportation of camp equipage and provisions, but soon they were abandoned and resort was had to "glade boats," a light craft used by hunters and Seminole Indians. They, too, had to be abandoned, and then each man had a pack of provisions assigned him and they struck boldly into the swamp. Had I had the least conception of what these men were to endure, I should not have permitted the effort to be made. They struggled along through muck and saw grass, exposed to swarming insects and innumerable reptiles. Speak-

Camp in the "Flat Woods."

ing of reptiles, before they abandoned glade boats two of the men used a boat for a bunk one night. In the night they became aware of a third occupant, and that bed-fellow was a big snake. With alacrity they took to the swamp and left the bunk to the snake. I do not remember how many days they spent floundering through this morass, but at last they reached solid ground on the shore of the lake. They were out of food and so much exhausted that Mr. Hills told me they could not have struggled through another 1000 feet of such going as they had experienced. Their equipment and provisions had been sent to Fort Lauderdale, to be shipped aboard our chartered motor yacht to Lake Okeechobee. You can well appreciate the joy of these explorers when, after resting on the shore of the lake for about an hour, they saw the *Pearl* headed their way, laden with provisions, clean and whole clothes, cots, and other of life's comforts.

The journey over this route from the coast to the lake had never before been made by white men. I say by white men, for nobody knows where the Seminoles have been nor yet how they managed to traverse these wilds unscathed by saw grass and unbitten by reptiles. They go barelegged and barefooted. The Good Lord, "who tempers the wind to the shorn lamb," must have given these people armored hides.

This was the experience of one of our parties and was the hardest of all, but none of the others had reason to think they were out for a picnic. They did their work and did it well, and on the results we were able to make our report to the state authorities. This report is printed as Senate Doc. No. 379, 63d Congress, 2d Session.

In the main, the knowledge obtained confirmed the ideas which I advanced to the state authorities when I met them in Tallahassee, April 28, 1913.

To sum up our recommendations, as set forth in that report:

The vital suggestions were a canal from Lake Okeechobee to the St. Lucie River, about 25 miles long, 200 feet wide, 12 feet deep, to carry off the flood waters poured into the lake by the Kissimmee River and other northern tributaries.

To insure that the floods should take the route thus provided, we recommended that locks should be placed in each of the canals heretofore constructed, or hereafter to be constructed, leading from the lake, so as to prevent any flow of lake water through those channels except what would be needed for purposes of navigation and irrigation.

The fall from Lake Okeechobee to the St. Lucie River, when the low lake stage is 16 feet above sea level (the high stage is 19 above sea level), is 15.2 feet. Allowing a slope of two-tenths per mile in the canal and taking the elevation of the St. Lucie River at the discharge end of the canal as + 0.8, we have a head of 11 feet; we figured the minimum discharge through the canal as 5000 cubic feet per second, and the resulting electrical horse-power on 80 per cent. efficiency as 5000 net. Such a potentiality in a land where there is no coal and where firewood is scarce is an asset of very great value.

The value of these Everglades lands when drained is great beyond all question, but in my judgment they must be used to produce other things than semi-tropical fruits and garden truck. If this vast area was devoted to raising oranges, grape-fruit, and such other fruits as the soil is suited to, the yield would far surpass any human demand for it, and a glutted market would be an unprofitable one. But these lands will produce many of the staples, such as corn, broom corn, alfalfa, etc., and the meat supply can be greatly augmented by the cattle which may be raised in tremendous number in this land where there is no winter and where Nature offers a continual food supply for graminivorous animals.

The work that we recommended as desirable for progressive accomplishment would cost $22,400,000, but we recommended that the development should only proceed so fast as to keep ahead of actual demands of population.

The exploitation of the Everglades by land speculators has given a very unsavory reputation to these lands. I have never had occasion to know the facts in the case, but it has been given out as a fact that 40,000 persons had bought Everglades lands under promise that they would be drained and made fit for cultivation. The natural inference is that the retail venders of these subaqueous lands had wilfully and viciously misrepresented the facts in the case, and that they did greatly exaggerate the virtues of the soil they were selling is abundantly shown, but it is also a fact that men who bought large tracts from the state made the purchases under assurances from the state officials that the lands would be drained. These assurances were made by officials who were ill advised and too optimistic. It was only after floundering along for years without adequate knowledge of the facts, the difficulties, and the proper remedies to be applied that the Governor and his associate trustees of the Internal Improvement Fund of the State of Florida decided to call into being "The Florida Everglades Engineering Commission." Nor do we who composed that commission claim to have exhausted the subject. This is brought out clearly on page 42, in this language: "Let no one vainly imagine that this report, or the report of any commission similarly instructed, can be the last word on the subject. On the contrary, such a report can only be the beginning of information. Patient and continuous study by the state's officers, and especially by the farmer, must proceed for a generation."

Transitman and Leveller.
(Hendrickson) (Pynchon)

After deducting time lost in preparation for our work, and in assembling its results for the report, our investigations covered only four months.

One feature of the proposed Okeechobee-St. Lucie Canal is worthy of mention. That canal and Lake Okeechobee will furnish 57 miles of a 12-foot waterway across the state, leaving 62 miles of smaller canal, Lake Hickpochee, and the Caloosahatchie River to be improved to give a trans-Floridian barge canal from the Atlantic to the Gulf of Mexico. The voyage around the end of the peninsula between the points connected by this barge canal (that is to be) is over 300 miles. To cover all of the points discussed in our report would be to reproduce the report, for therein we tried to elucidate the facts with the fewest words that would make them clear.

Before departing from the Everglades, I will reproduce some verses which I have seen in print describing somewhat poetically that vast expanse as seen by day and by night:

"THE EVERGLADES.

Across the widespread Everglades—
With its myriad host of saw grass blades,
And never a shrub, or vine, or tree,
To fix a spot on the grass-grown sea
That stretched away till the sea and sky
Seem'd to have met, to the far-strained eye—
The last slant rays of westering day
Had passed, with glow and glory, away;
And shades and shadows, mixed and blended,
Made the night of a day that is done and ended.
All overhead in the limitless blue
A sparkle of starlight filtered through
The mantle of circumambient air,
And naught could have made a night more fair,
Unless across the vasty dome
The crescent moon had deigned to roam.
Now we had journeyed all day long,
Hearing the engine's monotonous song,
While looking east or looking west,
The desolate scene our souls oppres't.
There was never the sign of a living thing,
Save life that throbs in the bird on the wing,
As we traversed a channel man had made
Across the widespread Everglade.
A channel through rock and muck and turf
To join a lake with old Ocean's surf,
And Okeechobee's waters flowed
Through the hollow way of this liquid road.
But all of a sudden, out of the dark,
There glowed and glimmered, spark after spark,
And all around, ahead and astern,
Countless lights began to burn.
Till it seemed, just then, to our dreamy gaze,
That the lights of a city began to blaze:

Lights in the windows of countless homes;
Lights that glowed 'neath palatial domes.
But the way those lights would flicker and wink
Filled us with wonder; just to think
Of the marvelous torches God supplies
To these tiny, light-winged fireflies.
But we thought beyond this fairy scene,
And saw a vision of what it will mean
To wrest for man this vast domain
Which for ages gone has tenantless lain,
Save for creatures that creep and crawl
O'er a surface held in water's thrall.
But we know, some day, that lights will show
Just where we saw the fireflies glow,
And that each of these lights will mark and tell
Of a home where comfort and love indwell,
And children will play in gardens of flowers,
And Florida say, 'This fair land is ours.'"

Tallahassee, Capital City—why mention that ancient town in connection with drainage? It is built on hills, its rains run off quickly, and, speaking aqueously, it is a dry town; how really wet it is I know not. But, be that as it may, Tallahassee is the seat of state government, and state government is inseparably connected with the Everglades. Without wise direction from that seat of power, the Everglades will never realize the poet's dream of many happy homes amid gardens of flowers. The powers centred in Tallahassee must set the stamp of their approval upon wisely-developed plans for the work, and they must secure the moneys necessary to carry out those plans upon a financial scheme which will so safeguard the purchasers of the state's securities that bonding houses will not look askance and shy away from such offerings.

But there is more of interest to Tallahassee than its Capitol. It is a picturesque old town; there are homes there generations old, with an air about them of the ancient régime, dignified ease and social consequence. There are wonderful live oaks in public squares and along shady streets with Spanish moss pendant from their giant arms. There are roses in Tallahassee, profuse in their bloom and delicious in their odor. It is a quiet old place in which one weary of the rush and bustle of life in our modern cities can find rest and time for reflection. One might almost call it a dead town. Once, when I was going there, a friend, who knew the place better than I did, asked where I was going. I told him, "Tallahassee." "Well," he said, "when you get within ten miles of it your leg will go to sleep." The deadest place within the city limits is the old cemetery, an interesting "God's acre." The first settlers sleep quietly there. Among the tombs were many bearing my surname. The epitaph on one tomb thrills one, for it tells that the dust beneath was once the living son of Murat, Napoleon's great cavalry leader. The name on the tomb is Napoleon Achille Murat, Prince of Italy. He was born in Paris, 1801, the son of Murat and the great Napoleon's youngest sister, Caroline. When Murat was driven from the throne of Italy this son was sent to Austria and there educated. When the power of his family was broken he came to America, purchased land in Florida, and became a planter; was mayor of Tallahassee. He married a daughter of Col. Byrd Willis, of Virginia. Many interesting stories are told as being characteristic of the man. He was very hospitable. It was his delight to have guests at meals. When his fortune was broken he could not overcome his hospitable instincts. It is said that on one occasion he brought home guests when the larder was empty. When he was advised of the facts he told the cook to go out to the pen, cut the ears off the pigs, and make a stew. I have heard that "One can not make a

A Seminole settlement.

silk purse out of a sow's ear," but never before have I heard of making a stew out of that organ. With this historic example in evidence, who shall say it can't be done?

In 1911, Senate Doc. No. 89, 62d Congress, First Session, was published. This contains a very interesting compilation of acts of Congress and of the state Legislature, and other papers, state and national, relating to the Everglades of Florida and their reclamation. This document contains a great deal of valuable information. If it is compared with the report contained in Senate Doc. No. 379, 63d Congress, Second Session, a very radical contradiction of conclusions and engineering methods is immediately manifest. This Doc. No. 89 shows that by Act of Congress, approved September 28, 1850, upwards of 20,000,000 acres of land have been patented to Florida. It may interest Philadelphians to know that a former citizen, Mr. Hamilton Disston, bought 4,000,000 acres of these lands in 1881, and on February 26, 1881, the said Disston entered into contract to drain all of the overflowed lands in the state of Florida belonging to it, and lying south of Township 23 and east of Peace Creek. Under an amended contract, dated August 17, 1888, the Disston Company was to receive one acre of land for each 25 cents' worth of drainage work done under the contract. Following this contract

Working a passage on a "Glade boat."

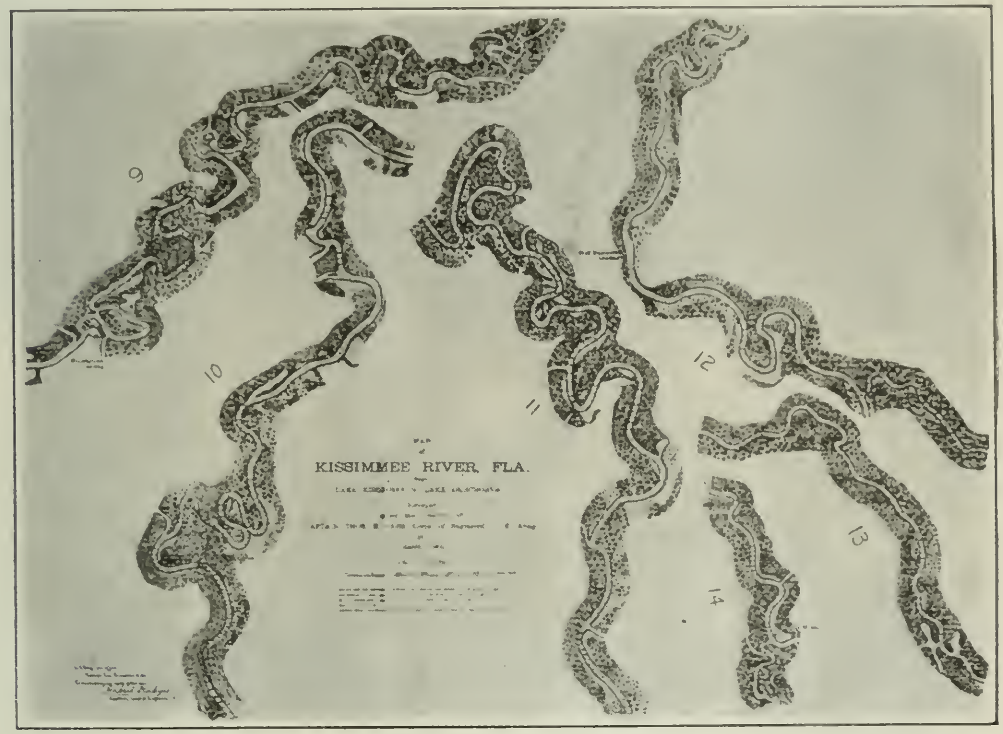
through to its final abandonment would be out of place here. The earliest work done under this contract was north of Lake Okeechobee, in the vicinity of Kissimmee. Kissimmee is located upon the north side of Lake Tohopekaliga, which is the head water of the Kissimmee River, and a beautiful sheet of water. In this lake are two lovely islands, one called Flemings Island, the other Paradise Island.

It was necessary that we—Messrs. Leighton, Perkins, and Randolph—should have a pretty good idea of the territory drained by the Kissimmee River, the run-off from which is discharged into Lake Okeechobee. To acquire this pretty good idea, we chartered the small steamer *Lilly*, owned and operated by Captain Clay Johnson, of Kissimmee. Captain Clay Johnson is one of the features of the Kissimmee region. If John Hay had known him he would have immortalized him in verse, or, had he been known to Mark Twain, one more character sketch would have found its place among the friends whose pen-pictures are in the great gallery delineated for us by that inimitable artist. A voyage with the Captain up or down that crooked river would serve to equip the voyager's memory with the lore of the land and the picturesque vocabulary of a voluble boatman.

Tombs of Prince Napoleon Achille Murat and his Wife.

We left that young city at 7:42 A.M., July 17, 1913, steamed across Lake Tohopokaliga, eleven miles to the Southport Canal, dug under the Disston contract, and through this canal four miles into Lake Cypress, across it into Hatchenaha Canal, which led us into a lake of the same name, from which we issued into the Kissimmee River—a stream of many convolutions—as shown in the illustration below.

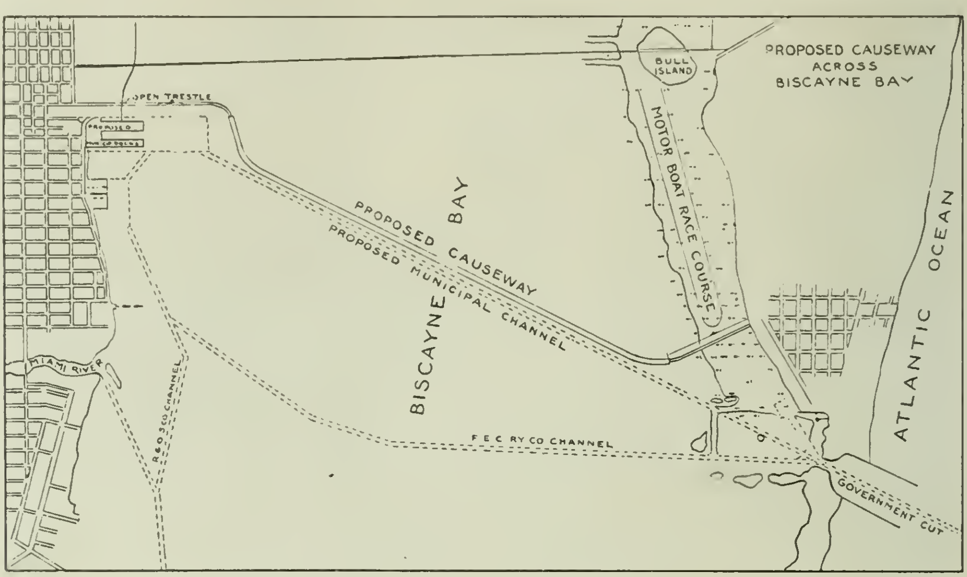
Well, it was an interesting and instructive voyage of 137 miles, ending in Lake Okeechobee at 3 P.M. of the second day. This voyage and a study of maps prepared by the War Department enable me to submit a report in December, 1913, showing how this river can be shortened from 137 miles to 109 miles, made commercially navigable and at the same time drain a vast area of valuable land.



Characteristic windings of the Kissimmee River.

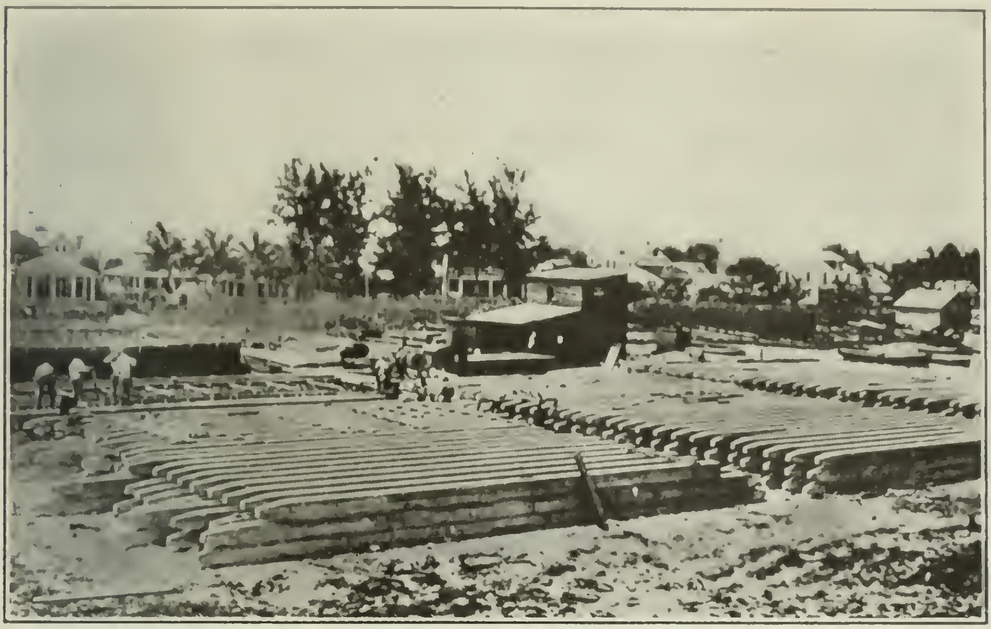
The parties who employed me to make this investigation and report were nearly mobbed by people who want these lands held in their present condition as cattle ranges. They do not own the lands, but they own herds of cattle and they need free pasturage to increase the profits of the business. I was told the owners of these lands had built fences about their holdings, but to no purpose, as the fences were cut down and the range kept open.

I cannot leave beautiful Lake Tohopokaliga without telling of a delightful episode in my experience. On Saturday, November 8, 1913, I visited Kissimmee to secure further data for the report which I had been employed to make. I hunted up Captain Clay Johnson and was able to add the desired information to my stock of knowledge. I went to the dock to see high-water marks, and, while thus engaged, a gentleman approached and introduced himself to me as Mr. Micklejohn and invited me to dine with him. He explained that he lived on the island, and invited me aboard his motor boat; there he introduced me to his wife, and soon another gentleman came aboard, who was introduced as Mr. Frank Vans Agnew. The island was perhaps four miles from the dock, and our craft made its way through a choppy sea, beneath a threatening sky; we landed and reached a most attractive home just as the storm broke. It was a home with many comforts and no extravagances. To my surprise, it was electrically lighted by a little domestic electric light plant, operated by a 5-horsepower gasoline motor. I spent a charming evening, and the storm had abated and the moon come out when I said good-bye to Mrs. Micklejohn, and the gentlemen manned and cranked the motor boat and took me back to Kissimmee in time to catch the night train for Jacksonville. Mr. Vans Agnew made me the bearer to Mrs. Randolph of a basket of splendid island-grown fruit. Now, if the island is dwelt upon at all, strangers enjoy its pleasant

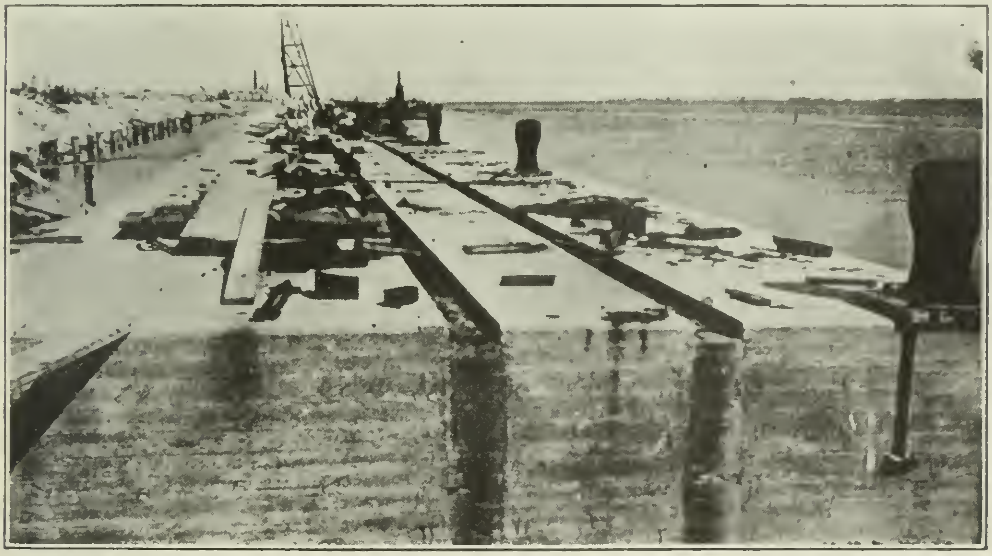


Map of Miami Harbor and Navigable Channel.

places, for Mr. and Mrs. Micklejohn, when the war broke out, went to the scene as Red Cross nurses; and Frank Vans Agnew added new dangers to a life of adventure. First, he enlisted in the cavalry, and, when he found how limited was its field of action, he got transferred to infantry and was put into the detachment of bomb-throwers and soon became chief bombardier of his



Concrete piles used in Miami Dock.



Miami Dock under construction.

regiment. Is he alive to-day? I do not know, but I hope so. He wrote letters to his kindred in this country and in England, and

Hydraulic dredge *Florida*.

A "screw pine," Miami.

many of these were published in *Scribner's* as "Letters of a Bomb-thrower." He lived with the Cossacks on the Steppes of Siberia for five or six years. He was one of Roosevelt's Rough

Riders, and now he has seen real war, and I hope he may live through it and dwell once more on his beautiful island and enjoy the fruits of peace, even though the horrors and the thrills of combat shall never fade from his memory.

Well, I was to find that Florida had need of engineers for work other than drainage ditches and canals for navigation.

Miami wanted a harbor and an outlet to the sea, and, inasmuch as these wants had been felt for a long time and a paternal Government declined to satisfy them, Miami remembered that "the Lord helps those who help themselves," and the memory inspired the resolution to try a little self-help; but somebody had to plan the outlet to the sea and the dock, and I seemed to be the somebody who was needed, and I was instructed to go ahead. When the bonds were voted and said paternal Government saw that this young city by the sea was in earnest, it appropriated the funds necessary for deepening and widening the entrance to Biscayne Bay. The city's work, now nearing completion, comprises a channel three miles long, 100 feet wide, and 18.8 feet deep, a turning basin, a concrete dock 1000 feet long, of a design never before built. The reinforced concrete floor is carried on

Some of the varieties of Florida fish.

bents spaced twelve feet centre to centre. There are five reinforced concrete piles in each bent, and on these is a massive reinforced concrete cap. I modestly assert that it is the finest dock on the Atlantic coast between Hampton Roads and Key West. Miami has had a wonderful growth; it is about 16 years old and it has a population of about 20,000. It is destined to rival Los Angeles.

Of course, the stupendous drainage project of Florida is that of the Everglades, but there are others of some consequence. The most important of these others is the Upper St. Johns River Drainage District, containing 262,000 acres. The work that it is proposed to do, however, will benefit about as many more acres. This project, upon which I reported in 1915, has been held up for over a year by the War Department, upon the plea that draining these marshes would injure navigation upon the St. Johns River. I have been able to convince the army engineers that this is an untenable theory, and nearly all of the arguments by which this change of view was brought about are based upon, and sustained by, facts in possession of the War Department and taken from records to which I was given access. Army engineers—at least those with whom I have come in contact—will not suppress facts which are within their keeping, although they may reach conclusions sometimes that are illogical. However, one of our human frailties is to think that he who differs with us is mistaken and wrong-headed. The permit for this work issued December 22 last, and we hope soon to make inapplicable the name " Ocean Prairie," which attaches to this tract.

In conclusion, let me advise all prospective purchasers of Florida lands to see what they propose buying, either with their own eyes or the eyes of a thoroughly reliable and experienced person delegated to act for them. Buying " a pig in a poke " is a safe venture compared with buying land " sight unseen "—be that land in Florida or in any higher latitude.

THE PHYSICAL BASIS OF COLOR-TECHNOLOGY

BY

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I. Spectral Analyses and Their Uses.

INTRODUCTION.

A perusal of the literature on colored media and a general acquaintance with color industries have led to the conclusion that the chemistry of such substances greatly dominates the physics in color-technology. In fact, much of the physics of color is so little used in some of these activities that it is either not generally understood by color-technologists or its value is underestimated. Spectral analyses, the quantitative determinations of the spectral characteristics of colored materials, provide the foundations for many important aspects of color-technology, and without such data some work progresses more or less blindly. With such data, and those derived from less analytical methods, many interesting facts of color-technology can be bared and various factors can be determined which are unapproachable from the viewpoint of chemistry or from ordinary visual inspection. Having available a great deal of data resulting from the study of the physics of color and its applications, it appeared of interest to present some of the spectral analyses which might be helpful to others, and especially to point out some of the many uses of such data. This has been done in the following paper.

THE ANALYSIS OF COLOR.

Of the various methods of analyzing color, that of the spectrophotometer is the most analytical, and it provides data of far greater usefulness in the physics of color than the data which are yielded by any of the other methods. By this method the reflection (or transmission) factors of the coloring media are determined for radiant energy of all wave-lengths in the visible spectrum. When these are plotted we have the spectral reflection (or transmission) curves for the visible spectrum. By the same method the spectral character of an illuminant may be obtained. By multiplying the relative energy-values of the various wave-lengths of any illuminant by the corresponding visibilities of radiation, the special luminosity-distribution curves are obtained for the given illuminant. These latter will vary with the illuminant and are often of greater importance than the spectral energy-distribution curves from a visual viewpoint. It is obvious that by multiplying corresponding spectral values the spectral energy-distribution and luminosity-distribution curves of any colored medium may be readily obtained for any illuminant. Such data and their uses will be presented later.

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* Communicated by the Author.

The monochromatic colorimeter, which yields data in terms of hue, saturation, and brightness or luminosity, is the most generally analytical among the so-called colorimetric methods. This method analyzes color from the subjective viewpoint and yields data which may be readily visualized by one possessing some experience and an acquaintance with the spectral hues. From a subjective viewpoint the monochromatic colorimeter appears the most feasible method upon which to base a scientific nomenclature of color—an urgent need at present. An advantage of this method lies in relating the analyses to the constant and reproducible visible spectrum; however, in determining the saturation (unity minus the per cent. white) a white light is necessary, and this has not been standardized. A further difficulty lies in the unsettled state of color-photometry, which is necessarily involved in determining the luminosity or reflection and transmission factors. For these reasons at this time no data will be presented as obtained by this method which appears so promising.

The trichromatic colorimeter yields analyses in terms of three more or less arbitrarily chosen primary colors; namely, red, green, and blue. This is based on a well-known fact of color-mixture; *i.e.*, that any color may be matched in hue by a proper mixture of these three properly-chosen primaries. Young built what has later become known as the Young-Helmholz theory of color-vision chiefly upon facts of mixture of these three primaries. This method is not very analytical, and it is quite difficult to visualize a color from an analysis by this method. Furthermore, the data are often misleading to those not thoroughly familiar with their limitations, because the comparisons are made from the subjective standpoint.

Besides these chief methods, there are many kinds of colorimeters devised for special purposes—useful in their places, but yielding data of little general value analytically. Some of these are merely tintometers, consisting of a series of tints of various gradients in hue, saturation, and reflection (or transmission) factors, designed chiefly for special purposes, such as confining a given product within certain limits as judged by color.

Owing to the indefiniteness and limitations of the data yielded by most of these so-called colorimetric methods, and the difficulties attending the use of the monochromatic colorimeter at present, this paper will be confined almost entirely to spectrophotometric data and their uses. Many instances arise when the degree of absorption for ultraviolet and infra-red rays is of interest. The former can be determined readily by spectrophotography and the latter by means of such energy-measuring instruments as the bolometer or thermopile. Other methods are available, which may readily be ascertained if necessary.

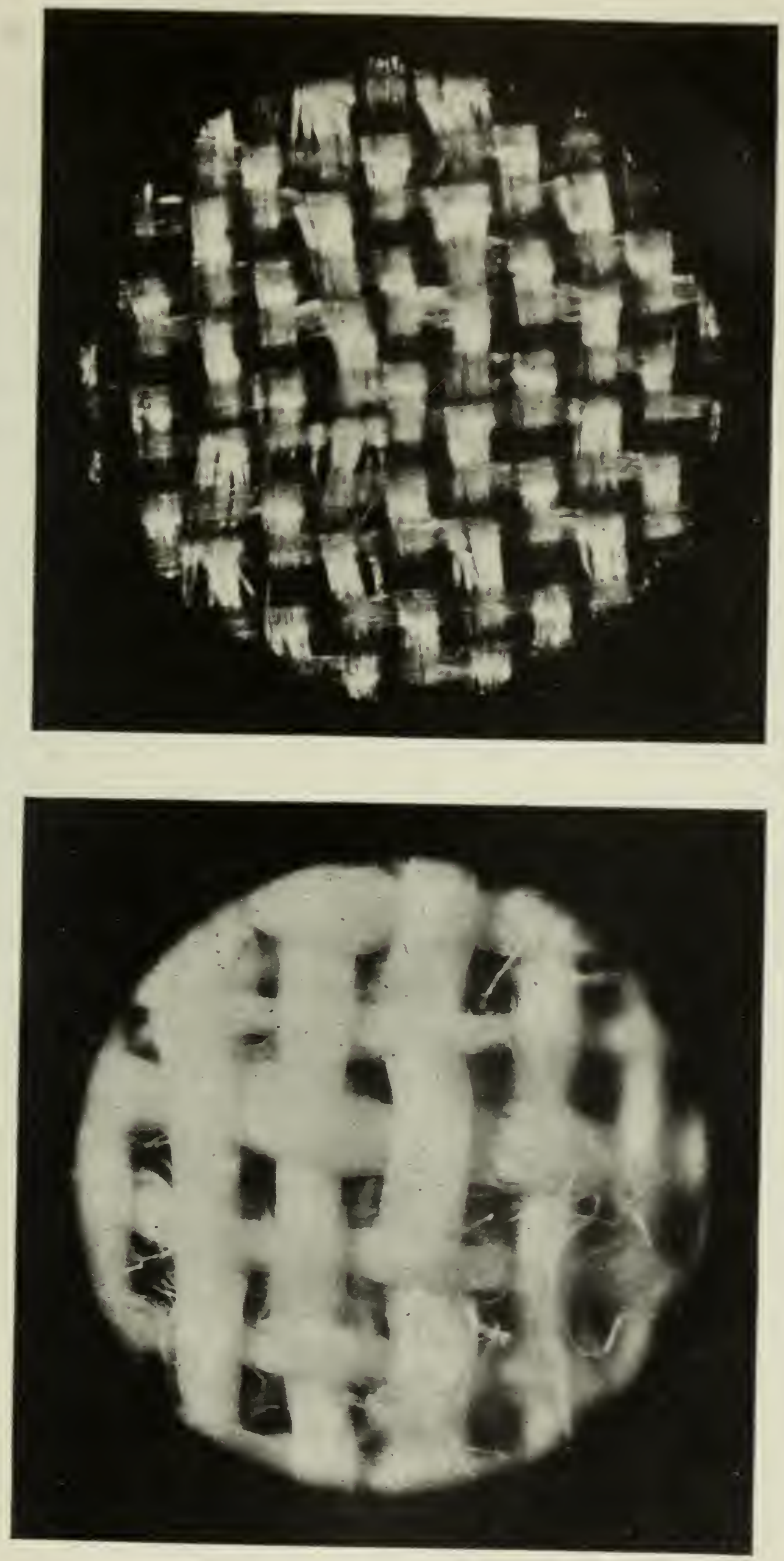
COLORED MEDIA.

For the purpose of this paper three classes of colored media will be represented and discussed; namely, pigments, dyes, and vitrifiable colors or colored glasses. Pigments are distinguished from dyes by their insolubility in their vehicle, while dyes are soluble. This distinction may appear arbitrary, especially in some cases; however, it is employed to some extent and is a convenient classification. Pigments may be distinguished from paints in that the latter are pigments in a vehicle or medium. Vitrifiable colors are those which impart color to glass and to similar substances. Among pigments are found two general classes: one in which each particle is homogeneous, and the other in which a colorless base has been colored by depositing coloring matter upon it. Colored media vary in many physical characteristics, such as opacity, fineness, and refractive index, and they may be considered as varying in "coloring power." However, these facts are of interest only incidentally in this paper.

The color of a pigment in a finely-divided state, whether the particles are separated by air or by a vehicle, is due to innumerable selective reflections from, and transmissions through, the minute particles. If the powdered pigment is given a smooth surface by pressure it does not appear as pure in color as when it is loosely packed, because in the latter case a greater proportion of the incident radiant energy is able to penetrate more deeply into the body and becomes colored by selective reflections and transmissions. Radiant energy is regularly reflected from even the small surfaces of the particles of pigment, and in those cases where the minute areas of surface are properly oriented this regularly reflected light does not find its way farther into the pigment, but is reflected practically unaltered in spectral character as compared to that energy which penetrates farther into the mass. Thus there is always reflected from pigments some radiant energy which is practically unchanged in spectral character, which accounts partly for the general lack of purity of the colors of pigments. It is seen that the character of the surface is important. Furthermore, the refractive indices of the pigment and of the vehicle (air in the case of dry powders) are of importance, because the amount of light regularly reflected from a surface is dependent upon these refractive indices. A careful study of the influence of the vehicle upon the color of a paint should lead to interesting data from this viewpoint alone. Work has been done in physical optics which is of extreme interest in this connection, but a discussion of it will not be presented here.

Although careful observation will reveal the influence of the porosity of a pigment surface upon its color, an excellent example for the purpose of illustration here is the color of a white cotton fabric compared with that of a white silk fabric after both have been soaked in the same dye-solution. In Fig. 1 are shown reproductions of microphotographs of white cotton and silk fabrics as photographed against a black background. It is seen that the silk is more transparent than the cotton fibres; in fact, the cotton fibres are merely translucent, as compared with the transparency of silk fibres. The latter permit the radiant energy to penetrate more deeply, in general, than the cotton fibres; in other words, the cotton fibres by diffuse reflection turn the energy backward before it has penetrated very deeply. For this reason the silk fabric appears of a purer color compared with that of the cotton fabric dyed in the same solution, the result, in the case of the silk, being similar to that which would have been obtained with the cotton if the latter had been dyed in a more concentrated solution of the dye.

FIG. 1.



Cotton

Silk

Microphotographs of cotton and silk fabrics against a black background.

In a manner similar to the case of pigments the solvent appears to have certain influences upon the color of a solution of a dye, although this subject has not been thoroughly studied. The substance upon which a dye has been deposited by immersion is also of importance in spectral analysis, as is indicated by the case of dyeing cotton and silk fibres, Fig. 1. The transmission factor of a dye-solution is a simple logarithmic function of the depth of a given solution or of its concentration, but this relation varies with the wave-length, in general in no definite relation between wave-length and spectral transmission factor. For this reason no simple relation between total transmission and depth or concentration can be established. Such values of total transmission must be determined by direct measurement or by integration, as will be discussed later.

Colored glasses can be treated much in the same manner as dye-solutions. A given concentration of coloring material in a glass (that is, a given colored glass) apparently obeys the same law relating to thickness and transmission factor for a given wave-length as a dye-solution. However, it is not established that the introduction of various amounts of the coloring material (generally metallic oxides) results in corresponding concentration, as would be true in the case of dyes. In glass there is more or less chemical action, and the uncertain conditions of melting make this point difficult to decide.

The physics of the process by which glasses are colored by means of metallic compounds is not wholly clear. There are many chemical analogies which are of interest for their parallelism to the colors imparted to glasses by the metals in different states, but the reasons for the appearance of the colors cannot be considered as being thoroughly established. Garnett[1] has presented a very interesting discussion of the colors exhibited by certain glasses in which metallic oxides had been incorporated. It is a common supposition that the colors of certain glasses, such as gold red glasses, are due to the presence of very minute particles of metal. Solutions of some metals exhibit colors which are often exhibited by colored glasses in which the same metals have been introduced. Siedentopf and Szigmondy, by powerfully illuminating specimens of colored glass and colored colloidal solutions of metals obliquely, or at right-angles to the line of sight, were able to detect the presence of the metallic particles. Garnett's work explained some of their observations.

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[1] *Phil. Trans. of Roy. Soc.*, A, vol. 203, p. 385.

It is commonly considered that metals color glass in two ways: one by being in a state of true solution in the glass, and in the other by being in a colloidal state. An example of the former is copper blue-green glass, and of the latter, gold red glass.

In dealing with the physics of colored media from the viewpoint of the physicist one cannot avoid the conclusion that there is a wide application of physics to color-technology in many directions quite unexplored; however, such a discussion would be beyond the scope of this paper.

SPECTRAL ANALYSES OF PIGMENTS.

In presenting data which it is hoped will be of direct use to others only those colored media have been selected which are thought to be fairly constant in composition and representative. The spectral reflection factors of a group of dry powdered pigments,[2] commonly used in the paint industries and which from general observation appear representative, were determined by means of the spectrophotometer and the data are presented in Table I. The light was reflected from a thick layer of the powder, the surface being gently smoothed by means of a sheet of plane glass. Whites and blacks have been omitted, but these are by no means always neutral pigments. Whites are very commonly yellowish, and blacks (which are only approximately black, varying in reflection factor from 0.02 to 0.1) are often bluish or reddish. Although these departures from neutrality are not relatively great, they are sufficient to be detected by means of the spectrophotometer. Such small departures are readily detected by painting the inner surface of a box with such a supposedly neutral pigment and by viewing a white surface indirectly lighted by means of a light-source inside the box. The visible radiation suffers innumerable reflections [3] from the walls of the box, and that which illuminates the white surface is therefore much more colored than the pigment would appear under direct illumination. The spectral reflection factors of pigments are more difficult to obtain than the transmission factors of dyes in solu-

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[2] Kindly furnished by Sherwin-Williams Company.

[3] M. Luckiesh, *Trans. I. E. S.*, **8**, 1913, p. 61.

TABLE I.

Spectral Reflection Factors of Dry Powdered Pigments.

REFLECTION FACTORS FOR VARIOUS WAVE-LENGTHS.

	0.44μ	0.46μ	0.48μ	0.50μ	0.52μ	0.54μ	0.56μ	0.58μ	0.60μ	0.62μ	0.64μ	0.66μ	0.68μ	0.70μ
American vermilion	0.08	.06	.05	.05	.06	.06	.09	.11	.24	.39	.53	.61	.66	.65
Venetian red	.05	0.5	0.5	0.5	.05	0.6	0.7	.12	.19	.24	.28	.30	.32	.32
Tuscan red	.07	.07	.07	.08	.08	.08	.08	.12	.16	.18	.20	.22	.23	.24
Indian red	.08	.07	.07	.07	.07	.07	.07	.11	.15	.18	.20	.22	.23	.24
Burnt sienna	.04	.04	.04	.04	.05	.06	.09	.14	.18	.20	.21	.23	.24	.25
Raw sienna	.12	.13	.13	.13	.18	.26	.35	.43	.46	.46	.45	.44	.45	.43
Golden ochre	.22	.22	.23	.27	.40	.53	.63	.71	.75	.74	.73	.73	.73	.72
Chrome yellow ochre	.08	.09	.07	.07	.10	.19	.30	.46	.60	.62	.66	.82	.81	.80
Yellow ochre	.20	.20	.21	.24	.32	.42	.53	.63	.64	.61	.60	.59	.59	.59
Chrome yellow (medium)	.05	.05	.06	.08	.18	.48	.66	.75	.78	.79	.81	.81	.81	.81
Chrome yellow (light)	.13	.13	.18	.30	.56	.82	.88	.89	.90	.89	.88	.87	.85	.84
Chrome green (light)	.10	.10	.14	.23	.26	.23	.20	.17	.14	.11	.09	.08	.07	.06
Chrome green (medium)	.07	.07	.10	.21	.21	.17	.13	.11	.09	.07	.06	.06	.06	.05
Cobalt blue	.59	.58	.49	.35	.23	.15	.11	.10	.10	.10	.11	.15	.20	.25
Ultramarine blue	.67	.54	.38	.21	.10	.06	.04	.03	.03	.04	.05	.07	.10	.17

tion, because in the former case more or less energy is regularly reflected from the particles directly into the instrument. Care must be taken to avoid placing the pigment surface in such a position with respect to the slit of the instrument and to the light-source that an undue amount of regularly reflected visible radiation enters the instrument. The visible radiation which is thus regularly reflected is practically unchanged in spectral character as compared with that which penetrates into the interstices of the pigment, and is colored by innumerable transmissions through, and reflections from, the minute particles of pigment. At any angle some of the energy is regularly reflected from the minute portions of the surfaces of the particles which are properly oriented. This accounts partly for the general lack of purity of the colors of "opaque" pigments. The data of Table I are plotted in Figs. 2 and 3.

Spectral analyses in the ultraviolet and infra-red regions are often of interest in general color-technology. In the former case spectrophotography is the simplest method of attack, although the procedure is a tedious one if high accuracy is desired. It is necessary to establish photographic-density and pigment-illumination (or exposure) relations for various wave-lengths in order to obtain the reflection factors for radiant energy of various wave-lengths. Besides this, the ordinary precautions of photographic procedure must be taken. Another possible method is that which involves the use of the photo-electric cell. No systematic data on pigments in the ultraviolet region have been obtained, so none will be presented, although ofttimes it has been necessary to investigate this region for a particular pigment. It is well to recognize the importance of such analyses in cases involving ultraviolet light. An excellent example is zinc white, which absorbs ultraviolet energy quite freely.

The investigation of the infra-red region requires a more elaborate apparatus, although in many cases where total energy-absorption is of interest this can be obtained rather easily by means of the thermopile or bolometer. In fact, the ordinary radiometer, or even the thermometer covered with a pigment, yields data which have some uses in practice. Coblentz[4] has published interesting data on the reflection factors of various substances for infra-red and visible radiation of several wave-lengths. Among the substances which he studied were a number of pigments. The reflection factors of white pigments for energy of wave-length 4.4μ varied from about 0.1 to 0.4, and at 8.8μ and 24μ were considerably lower. These data especially emphasize the localized nature of absorption bands, as, for example, cobalt oxide is a better reflector of long-wave energy than zinc oxide, yet for visible rays it possesses an extremely lower reflection factor than zinc oxide. Lead oxide is a much more efficient reflector of long-wave energy than zinc oxide, magnesium carbonate, and other white pigments. The importance of the infra-red analyses is apparent in many practical activities. Coblentz has pointed out that a pigment which has a low reflection factor for energy of wave-lengths in the region of 8μ to 9μ is a better house paint in hot climes, because it re-radiates maximally in this region where the maximum radiation from bodies of temperatures from 20° to 25° C. is found. If the paint has a high reflection factor for visible rays it thus minimizes the heating effect of the incident energy. Such a combination is quite desirable in minimizing the heating effect of solar rays. This is merely one example of a vast number of interesting problems which could be met with more intelligence if spectral analyses were available.

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[4] *Bulletin Bureau of Standards,* vol. 9, p. 283.

SOME APPLICATIONS OF SPECTRAL ANALYSES OF PIGMENTS.

The chief use of the data derived from such spectral analyses is that of establishing the spectral character of the pigment. The general value of such data needs no defence, for it is the actual foundation of the pigment as a coloring material. Its purity is thus established; its influence in color-mixture may be predicted; the purity or desirability of a color resulting from various mixtures of pigments whose spectral analyses are available may be predetermined; and in many ways such data are useful. It is quite beyond the scope of a single paper to discuss all the physical uses of such data; besides, it is the intention to confine the discussion chiefly to aspects which are likely to be less commonly appreciated. For the latter purposes other data, such as the spectral energy-distribution in illuminants and the visibility of radiation of various wave-lengths, are necessary, therefore Table II is presented. The relative energy-values at various wave-lengths are given for four illuminants which represent nearly the extremes commonly encountered from the viewpoint of color. In the last column are presented Nutting's visibility data. There is no general agreement as yet among investigators regarding the visibility of radiation of different wave-lengths; however, the data of Nutting are sufficiently well established for the present purpose. His data were obtained by comparing the luminosity-values of known amounts of radiant energy with a standard source of luminous intensity by means of the flicker photometer. The values of luminosity were then reduced to a uniform or equal-

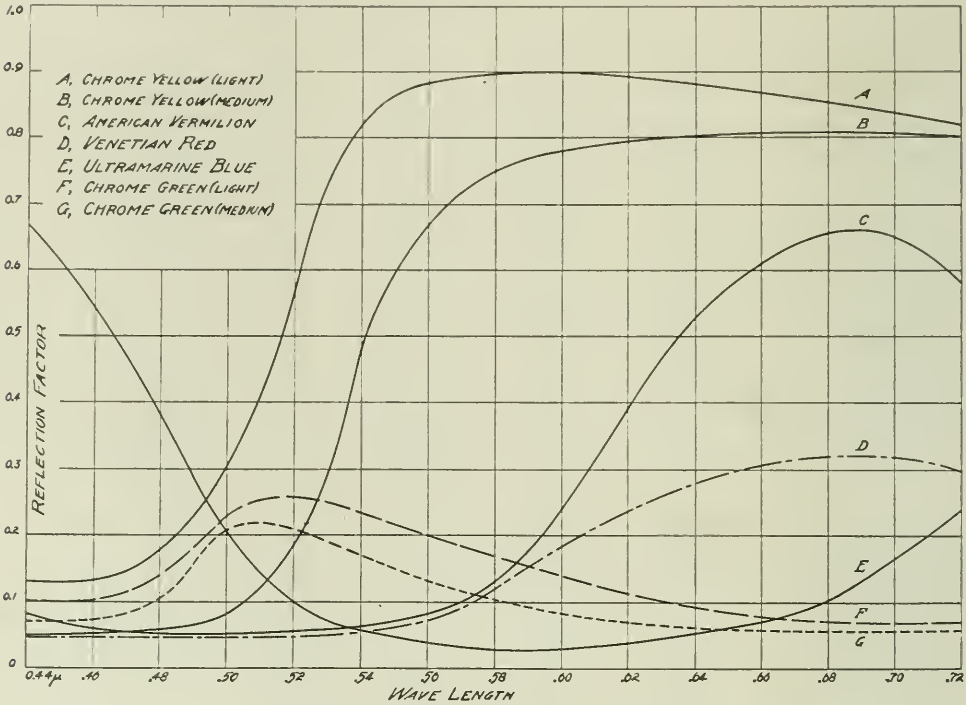
TABLE II.

Spectral Energy-Distribution in Common Illuminants and the Visibility of Radiation.

Wave-length	Blue sky	Noon sun	Tungsten (vacuum) incandescent lamp $7.9\frac{\text{lumens}}{\text{watt}}$	Tungsten (gas-filled) incandescent lamp $22\frac{\text{lumens}}{\text{watt}}$	Visibility of radiation (Nutting)
0.40μ	170	67	9	15	.002
.41	177	72	9.5	16.5	.003
.42	181	75	10.5	19	.008
.43	185	79	12	23	.012
.44	186	83	15	26.5	.023
.45	187	84.3	16.7	30	.038
.46	185	88	20	33.7	.066
.47	180	91	23.5	38	.105
.48	173	92	27	42.6	.157
.49	162	92.5	32.7	47	.227
.50	157	95	37.5	52	.330
.51	146	96	42.6	56.5	.477
.52	140	97	49	62	.671
.53	132	98	54.9	67	.835
.54	127	99	62.1	72.5	.944
.55	120	99	68.6	78	.995
.56	115	100	76	83	.993
.57	108	100	83.4	88	.944
.58	104	101	91	94	.851
.59	100	100	100	100	.735
.60	97	100	108	105	.605
.61	93	100	117	111	.468
.62	90	99	126	116	.342
.63	87	98.5	136	121.5	.247
.64	85	98	146	126	.151
.65	82	97.1	157	131	.094
.66	80	96	167	135	.051
.67	77	95.5	179	140	.028
.68	76	94	189	143	.012
.69	72.5	93.5	202	147.5	.007
.70	71	91.7	212	151	.002
.71	69.6	90	223	153.5	.....
.72	68	88	235	156	.....

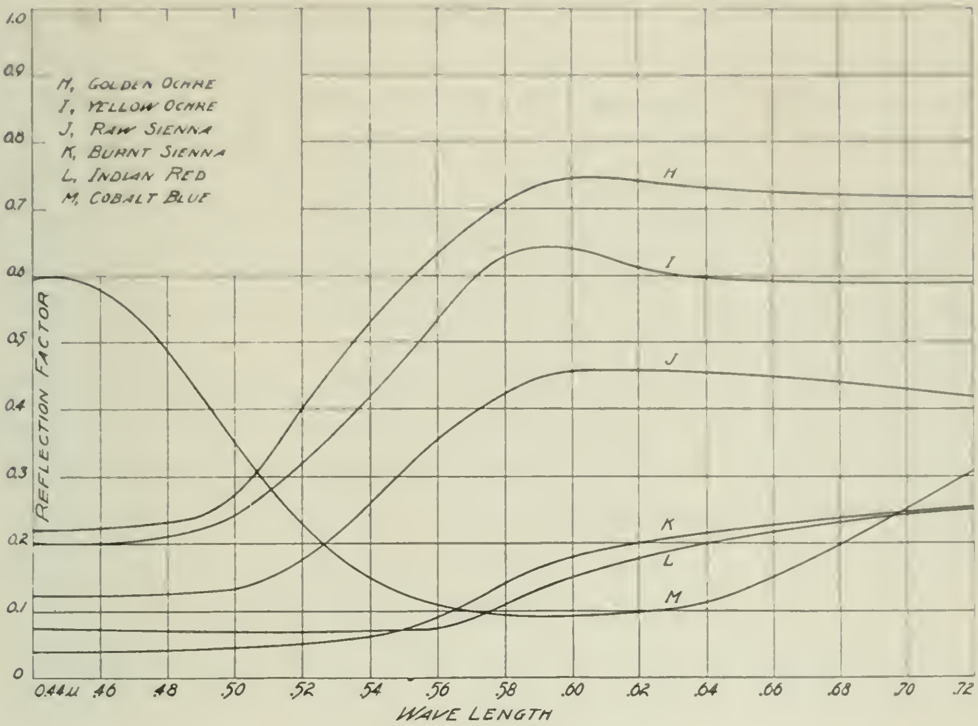
energy basis and are then termed visibilities. On multiplying each ordinate of a spectral energy-distribution curve of an illuminant, pigment, dye, etc., by the corresponding value of visibility the resultant data yield the spectral luminosity-distribution of the illuminant, pigment, dye, etc. Thus from the spectral energy and visibility data the relative spectral luminosity-values can be determined. On integrating the areas of the spectral luminosity curves the relative total luminosity-values of colored media and of illuminants can be obtained, and by dividing the area of one of the former by the area of one of the latter the reflection factor of the particular colored medium is obtained for the particular illuminant. Thus by computation the reflection factors of colored media can be obtained without any of the difficulties and uncertainties of color-photometry, for these have been involved in the determination of the visibility data. Such computations are found to yield results quite in agreement with those obtained by direct measurements of reflection (or transmission) factor. In fact, this method appeals very strongly to the author, especially because the spectral analyses should be available for many other reasons, so that reflection and transmission factors would be by-products.

Fig. 2.



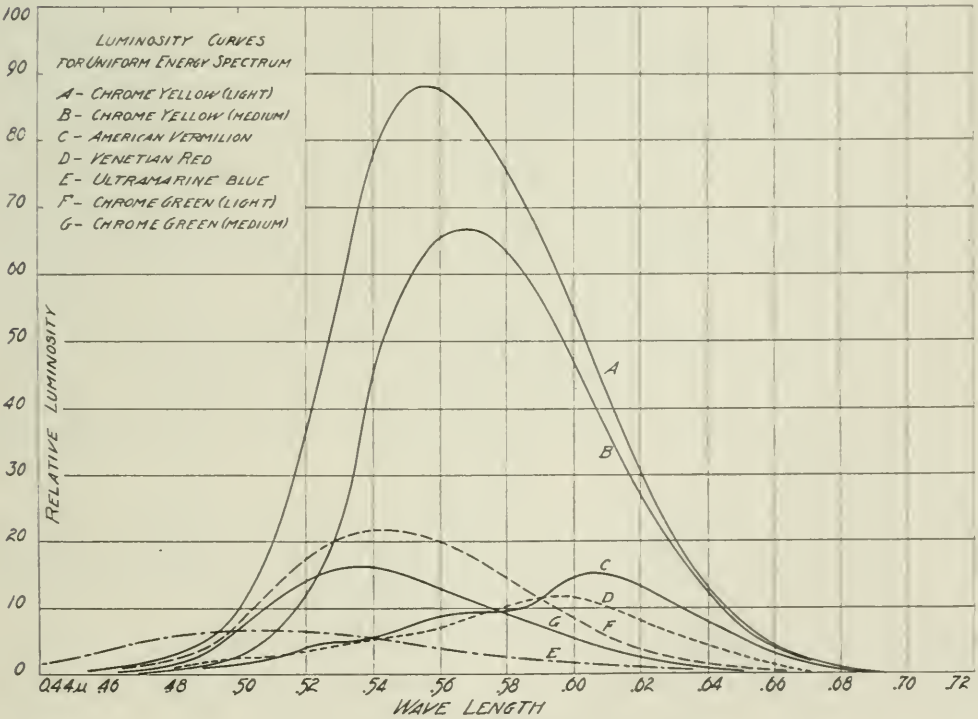
Spectral reflection-factors of pigments.

FIG. 3.



Spectral reflection-factors of pigments.

FIG. 4.



Spectral luminosities of pigments.

The spectral luminosity-distributions of the visible radiation reflected from pigments whose spectral reflection-factor distributions are shown in Figs. 2 and 3 and in Table I are presented in Figs. 4 and 5. These may also be considered as the spectral reflected energy-distributions for an imaginary illuminant of uniform spectral energy-distribution. Incidentally the light from the noonday sun approaches this ideal fairly closely, as seen by Table II, for in this table the energy-values of this ideal illuminant would be 100 for all wave-lengths, in order to be directly comparable with the other illuminants.

Reflection Factor.—In order to cover the general case more accurately, much of the foregoing discussion will be expressed mathematically, but, for the sake of clearness, reference will be made to these various curves in Fig. 6 for a specific case.

I = Spectral energy-distribution of an illuminant (tungsten filament at 7.9 lumens per watt).

J_λ = Energy-value of the illuminant at any wave-length, λ.

V = Visibility curve (Nutting's data).

K_λ = Visibility-value for energy of wave-length, λ.

L_I = Spectral luminosity-distribution of illuminant I.

P = Spectral reflection-factor distribution of a pigment (light chrome yellow).

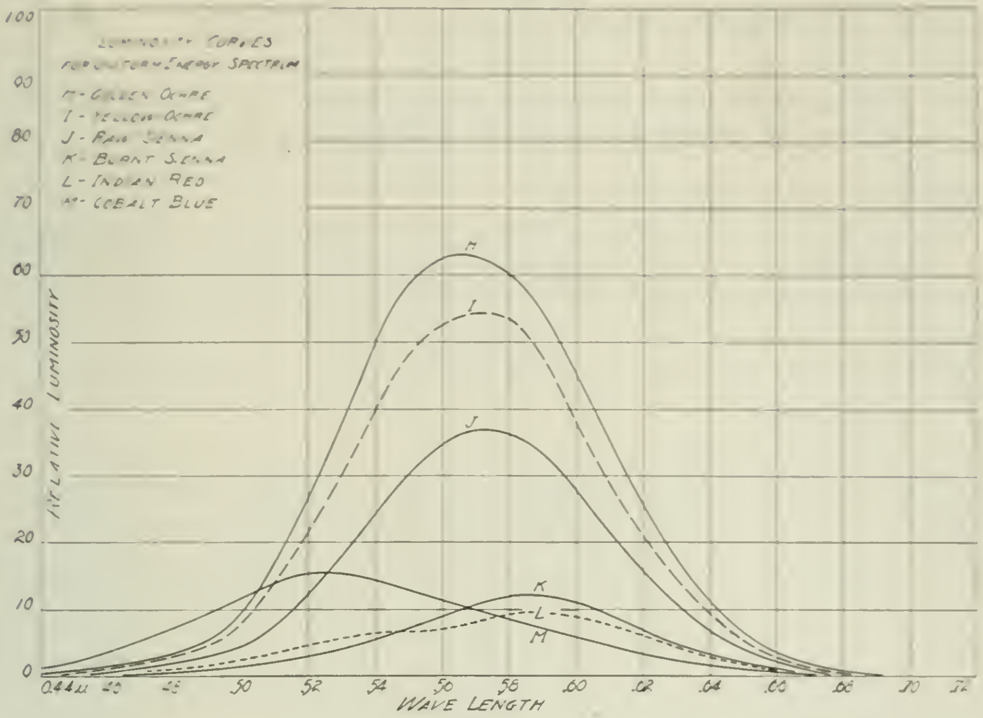
R_λ = Reflection factor of the pigment for energy of wave-length, λ.

L_P = Spectral luminosity-distribution of radiation reflected by the pigment.

For $\lambda = 0.52\mu$, $ad = J_\lambda$, $af = K_\lambda$, $ae = R_\lambda$, $ac = K_\lambda J_\lambda$, and $ab = R_\lambda K_\lambda J_\lambda$.

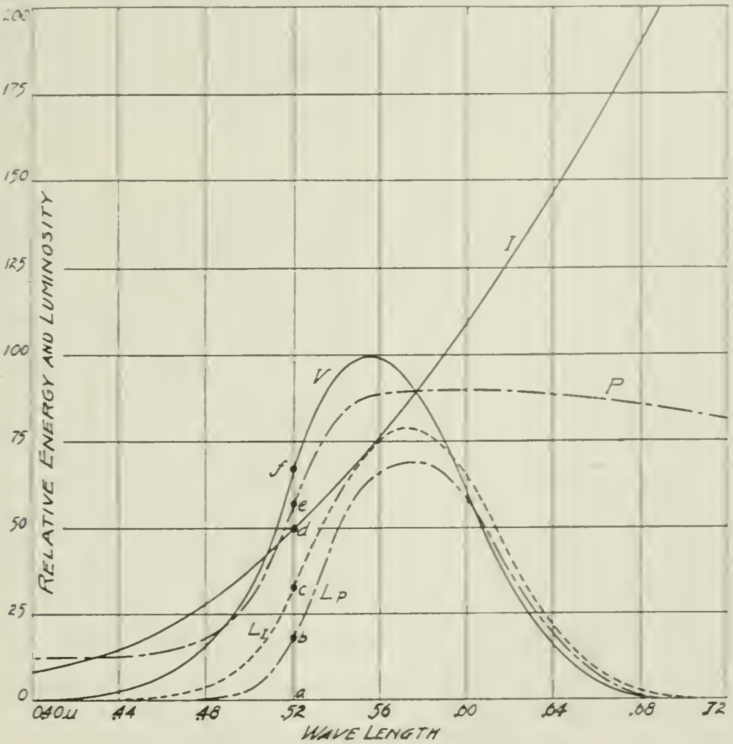
$\int_{\lambda_1}^{\lambda_2} K_\lambda J_\lambda d_\lambda$ = Area enclosed by L_I, which is proportional to the total luminous flux E, received by the surface between limits λ_1 and λ_2, hence is equal to CE where C is a constant of proportionality. If the total is desired, the limits, λ_1 and λ_2, are respectively the limits of the visible spectrum, which

FIG. 5.



Spectral luminosities of pigments.

FIG. 6.



A study of a pigment (light chrome yellow).

for most practical cases may be taken as 0.4μ and 0.7μ, although radiation is visible considerably beyond these limits.

$$\int_{\lambda_1}^{\lambda_2} R_\lambda K_\lambda J_\lambda d\lambda$$ = Area enclosed by L_p, which is proportional to the total luminous flux E', reflected by the surface (pigment P), and is equal to CE'.

If energy is of interest instead of luminosity, K_λ is eliminated and the limiting wave-lengths λ_1 and λ_2 are given the desired values.

$$\frac{\int_{\lambda_1}^{\lambda_2} R_\lambda K_\lambda J_\lambda d\lambda}{\int_{\lambda_1}^{\lambda_2} K_\lambda J d_\lambda \lambda} = \frac{E^1}{E} = R =$$ the reflection factor of the pigment P for the illuminant I, and λ_1 and λ_2 are respectively the wave-lengths at the limits of the visible spectrum. These limits could be expressed as 0 and ∞ without changing the result, because beyond the visible spectrum K_λ is zero.

Many useful data can be obtained by such computations when the spectral energy-distributions of pigments and of illuminants are available. These computations can be made for a sufficient number of wave-lengths throughout the spectrum, and the relative values of the integrals can be obtained by means of a planimeter from the plotted curves or more readily by summating the computed values.

Similar computations have been made for the group of pigments already introduced for four illuminants, including the ideal having a uniform spectral energy-distribution. These values are presented in Table III and Fig. 7. The values are given to the third decimal place, not with the belief that the absolute values are determined with such accuracy, but to show the differences as accurately as possible obtained by this method of computation. The relative values are perhaps accurate to the third place. It is seen that the reflection factor for a given pigment is not constant,[5] but varies with the illuminant. This is a point not generally appreciated, and, inasmuch as this difference exists, the suggestion is made that, for general purposes, reflection factors be given for an illuminant of uniform spectral energy-distribution. In cases of direct measurement of these factors the clear noonday sun sufficiently approaches the ideal, as will be shown shortly. In cases where other illuminants are used these should be specified. For direct measurement the Nutting reflectometer is an excellent instrument for most cases, although a flicker-photometer attachment would be helpful in the case of colored pigments.

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[5] M. Luckiesh, "Color and Its Applications," 1915.

TABLE III.

Absolute and Relative Total Reflection Factors of Powdered Pigments for Various Illuminants.

	Absolute				Relative			
	Uniform energy-spectrum	Noon sun	Blue sky	Tungsten filament $7.9\ \frac{\text{lumens}}{\text{watt}}$	Uniform energy spectrum	Noon sun	Blue sky	Tungsten filament $7.9\ \frac{\text{lumens}}{\text{watt}}$
American vermilion	0.137	0.137	0.117	0.117	1.00	0.99	0.86	1.29
Venetian red......	.106	.106	.095	.131	1.00	1.00	.90	1.23
Tuscan red.......	.107	.107	.101	.12	1.00	1.00	.95	1.12
Indian red........	.099	.099	.092	.112	1.00	1.00	.93	1.13
Burnt sienna......	.105	.106	.093	.127	1.00	1.01	.89	1.19
Raw sienna.......	.324	.326	.303	.366	1.00	1.01	.94	1.13
Golden ochre......	.578	.581	.548	.634	1.00	1.01	.96	1.10
Chrome yellow ochre...........	.328	.33	.289	.404	1.00	1.00	.91	1.24
Yellow ochre......	.486	.488	.46	.534	1.00	1.01	.95	1.11
Chrome yellow (medium).......	.542	.545	.496	.63	1.00	1.01	.92	1.16
Chrome yellow (light)..........	.76	.765	.70	.82	1.00	1.01	.92	1.08
Chrome green (light)..........	.19	.194	.19	.175	1.00	1.00	1.03	.93
Chrome green (medium).......	.136	.136	.142	.12	1.00	1.00	1.05	.88
Cobalt blue.......	.166	.162	.183	.13	1.00	.98	1.10	.79
Ultramarine blue..	.08	.074	.095	.057	1.00	.93	1.19	.71

The measurement of reflection factor directly is by no means standardized, and in the case of colored pigments this measurement is attended with many difficulties, such as the distribution of luminous flux upon the surface, its angular position with respect to the photometer, color-photometry, etc. A discussion of this has been presented elsewhere.[6]

In Table III the relative reflection factors of each pigment by itself for the four illuminants are presented, that for the uniform energy-spectrum being taken as unity. This gives a better idea of the magnitude of the variation of the reflection factor with the spectral character of the illuminant. These values are plotted in Fig. 8, and, as would be expected, the red and yellow pigments show relatively greater reflection factors for tungsten light than for blue skylight, with the values for sunlight (circles) lying between. It is interesting to note the proximity of the circles to

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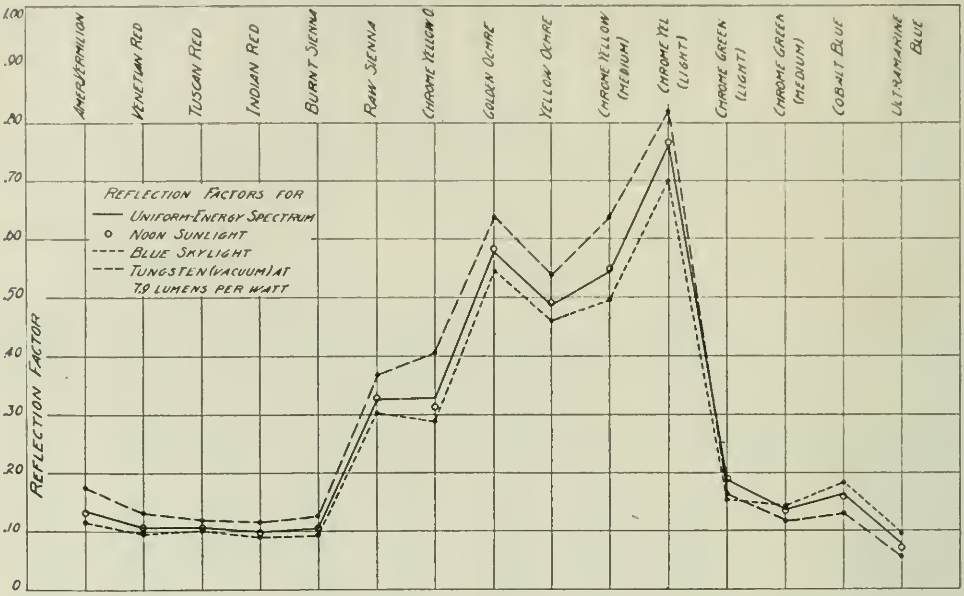
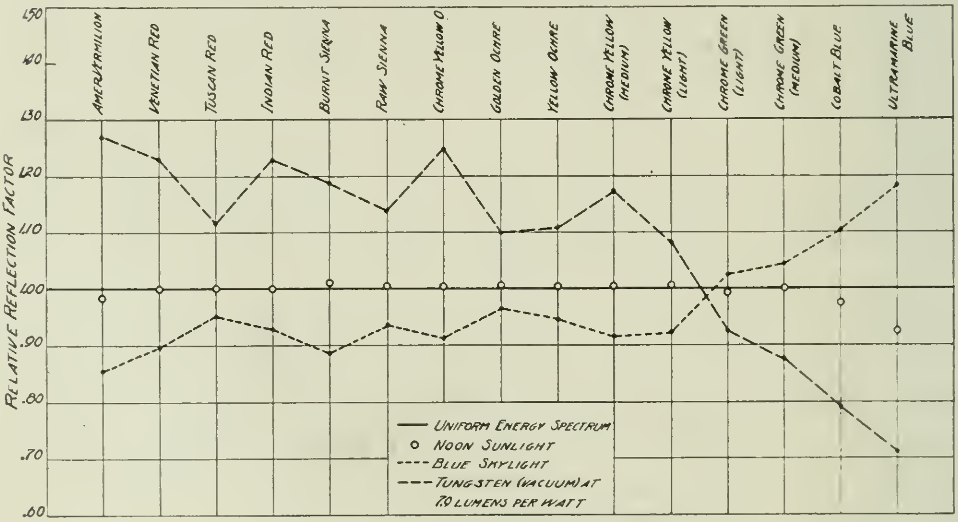
[6] M. Luckiesh, *Electrical World*, May 19, 1917.

FIG. 7.



Reflection-factors of pigments.

FIG. 8.

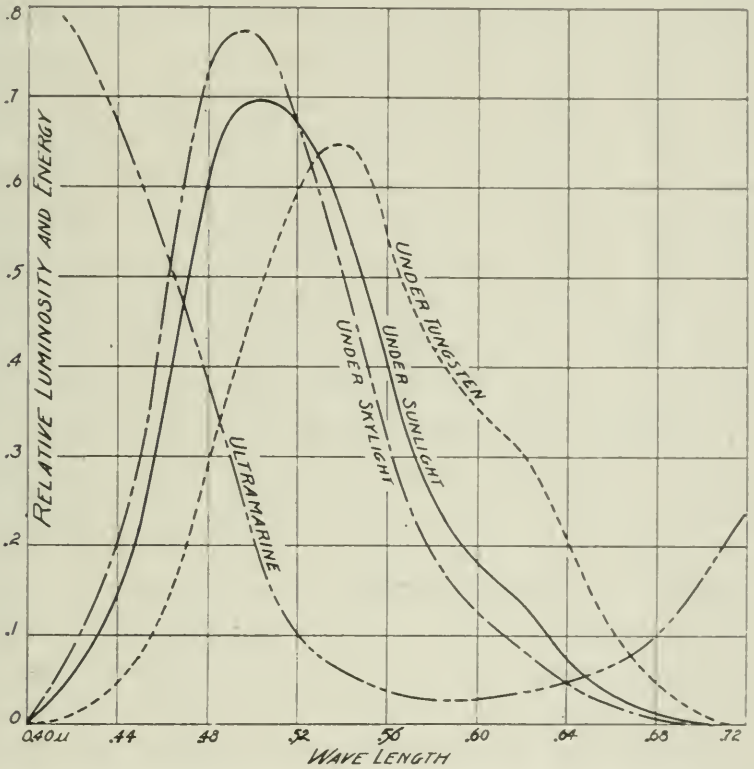


Relative reflection-factors of pigments.

unity, which represents the relative value of reflection factor in each case for the ideal illuminant having a uniform spectral energy-distribution.

The effect of the illuminant upon the appearance of the color is shown in Fig. 9, using, for example, ultramarine blue, whose spectral energy-distribution is shown. The spectral luminosity-distributions of this pigment for the different illuminants have been computed for equal total amount of reflected light (enclosed areas equal). Thus an idea of the appearance of the color can be formed, or, conversely, the reason for these different appearances under the three illuminants is manifest. Incidentally it is seen that this particular pigment is of a purer color under blue skylight than under either of the other illuminants. The wave-length of maximum luminosity is 0.495μ and 0.54μ, respectively, for the skylight and tungsten light. This wave-length of maximum luminosity is not necessarily the dominant hue of the color as analyzed by the eye or by the monochromatic colorimeter, although these are often nearly coincident.

FIG. 9.



Influence of the illuminant on the appearance of ultramarine pigment.

SPECTRAL ANALYSES OF DYE-SOLUTIONS.

The mixture of dyes is governed by the same subtractive principles of color-mixture as the mixture of pigments, although the greater number of dyes and the more exacting or delicate applications of dyes in industries, in the making of accurate filters, etc., make their spectral analyses of perhaps more importance than in the case of pigments. Certainly a knowledge of the spectral characteristics of dyes, as in the case of pigments, makes for an ease and certainty in making and in visualizing mixtures which cannot be enjoyed without such data. It is beyond the scope of this paper to present a complete discussion of the usefulness of spectral analyses of dyes or to present the spectral analyses of all the dyes available; however, a few representative analyses of dyes most common and perhaps most reproducible should be of value. These are presented in the following tables, roughly classified as to color. The highest accuracy is not claimed for these data, because it does not appear worth the effort necessary and because there is no indication that these dyes are, in general, constant in spectral characteristics as obtained from time to time in the market. For the same reason it has not been considered necessary to give values of concentration. From the data presented in the tables it is possible to obtain an idea of the spectral characteristic of a given dye-solution for any depth of the particular concentration employed and also for any relative value of concentration. In other words, from the data in the tables and the discussion which follows it is possible to be guided in the selection of dyes for many purposes. The data for the regions near the ends of the various spectra are uncertain to several per cent. For the study of a dye-solution throughout an entire range of depth and concentration by the method described later the spectral analysis should be obtained as accurately as possible. The present data on dyes were obtained by means of a spectrophotometer, the procedure being such as to eliminate all errors possible with the exception of the uncertainty naturally attending a limited number of observations and that due to ever-present scattered light. In all cases where not indicated otherwise the solvent was distilled water. The dyes were obtained from various well-known commercial sources. Among the solutions will be found a few solutions of metallic salts which are incorporated for their usefulness as filters. All data have been corrected for surface reflections and for the absorption of the glass cell by the method of substitution.

In Table IV are presented the spectral analyses of a number of dye-solutions commonly classed as red, although many are purple. The sharpness of the absorption or transmission bands is readily visualized from the data, although it is of advantage to plot the data in many cases. There are some excellently sharp bands shown; for example, that of eosine of moderate concentration. In some cases spectral analyses for two concentrations have been presented.

In Table V spectral analyses of a number of yellows are presented. It is noteworthy that there is no known dye which transmits only a narrow region near spectral yellow. The value of sharp absorption bands is seen when a fairly monochromatic filter is desired. For instance, a yellowish-green dye with a sharp cut-off on the long-wave side combined with a greenish-yellow dye with a sharp cut-off on the short-wave side will yield a fairly monochromatic green filter. Some of the dyes fluoresce, which from the point of view of color alone is of considerable interest. Fluorescein and uranine are among the many which fluoresce strikingly. It is interesting to study these by projecting a spectrum upon their upper liquid surface and by viewing the result both from above and from the side. The spectral analyses of potassium bichromate and cobalt chromate are included.

Among the greens in Table VI are a number of dichroics. In fact, a very common characteristic of green dyes is the exhibition of dichromatism. This can readily be ascertained by noting the energy-spectrum or spectral transmission characteristic of one of these dyes. If the transmission factor for red, say 0.7μ, is in any one case greater than that for any wave-length in the other regions of the spectrum (in the green for so-called green dyes), the solution at great depths or concentrations will appear red and therefore will be a dichroic. Naphthol green is an excellent yellowish-green dye. Among the greens presented, malachite, saürgrün, methylengrün, and neptune green exhibit dichromatism.

(*To be continued.*)

Tinning Cast-Iron. ANON. (*La Chronique Industrielle,* vol. 40, No. 291, p. 12, May 2, 1917.)—For household utensils only pure tin should be employed, and not tin and lead, as the latter forms poisonous salts with the acids of food products. To insure adhesion of the tin, the iron should be treated to remove the carbon, or otherwise it should be polished by mechanical means. To remove the carbon, the iron is coated with a layer of oxide of iron or manganese, or else the iron is enclosed in a box with the oxide and maintained at a high temperature to burn out the carbon. After four to six hours the iron is sufficiently decarbonized to permit the adhesion of the tin.

After this procedure the iron is cleaned with dilute sulphuric acid to which is added a small amount of blue vitriol. The iron is then immersed in molten tin; or, if the interior of a vessel is to be coated, molten tin with a little sal ammoniac is vigorously rubbed over the surface. It is preferable to heat the iron before applying the tin; and this must be done with care, otherwise the surface will be oxidized and impair the adhesion of the tin.

Tendencies of Motor Application. W. L. MERRILL. (*General Electric Review,* vol. xx, No. 6, p. 445, June, 1917.)—The first commercial use of electricity was in the field of lighting, next came railroading, while its use for industrial and power purposes has been a more recent development. Some of the first motor-drive installations made were replacements of steam engines; and in some cases the engine was left intact, so that if trouble developed with the new drive the original method could be resorted to. With the first installations of electric drive there became available a method of more conveniently measuring power than had been possible heretofore. With the old methods of steam drive, the charge was not segregated, the power being so interwoven with the general factory charges that very little was known of the actual cost of power delivered.

The next step in the application of motors was to divide mills or shops into several groups, which might be termed the semi-group drive. This eliminated some of the heavy belting and shafting maintenance; and from a review of conditions at that time it seemed that ultimate economics had been reached. Later, however, tests and data indicated that in a great many industries it was advantageous to still further divide the units of the drive. This consisted in driving with one motor a group of machines that work the same hours on the same product.

In certain classes of machines it has been the practice to employ the individual motor-drive, sometimes belted, sometimes geared, and, again, direct connected. Latterly, motors "built in" as an integral part of the machine drive have shown distinct advantages over the use of a separate standard motor, and the manufacture of many types of machines with self-contained electric drive seems to be rapidly gaining in favor.

PRESENTATION OF THE FRANKLIN MEDAL.
MAY 16, 1917.

At the Stated Meeting of the Committee on Science and the Arts, held March 7, 1917, the following resolutions were adopted:

"*Resolved*, That The Franklin Medal be awarded to Hendrik Antoon Lorentz, President, Royal Academy of Sciences, Amsterdam, Professor of Theoretical and Mathematical Physics in the University of Leiden, in recognition of his researches which have so largely contributed to laying on a new foundation our knowledge of the nature of light and in developing our ideas concerning the ultimate constitution of matter."

"*Resolved*, That The Franklin Medal be awarded to David Watson Taylor, Chief Constructor and Chief of Bureau of Construction and Repair, U. S. Navy, in recognition of his fundamental contributions to the theory of ship resistance and screw propulsion, and of his signal success in the application of correct theory to the practical design of varied types of war vessels in the United States Navy."

CORRESPONDENCE WITH MEDALLISTS.

The Franklin Institute
of the State of Pennsylvania
Philadelphia

Professor Hendrik Antoon Lorentz, President,
Royal Academy of Sciences,
Amsterdam, Holland.

April 12, 1917.

Sir:

I have the honour to inform you that The Franklin Institute has awarded you The Franklin Medal, founded for the recognition of those workers in physical science or technology, without regard to country, whose efforts in the opinion of the Institute have done most to advance a knowledge of physical science or its applications. The award is minuted as follows:

> "That The Franklin Medal be awarded to Hendrik Antoon Lorentz, President, Royal Academy of Sciences, Amsterdam, Professor of Theoretical and Mathematical Physics in the University of Leiden, in recognition of his researches which have so largely contributed to laying on a new foundation our knowledge of the nature of light and in developing our ideas concerning the ultimate constitution of matter."

The medal and accompanying certificate are being prepared and Chevalier W. L. F. C. van Rappard, your Government's Minister at Washington, has been requested to come to the Institute on the afternoon of Wednesday, May 16, to receive this medal and certificate, on behalf of his Government, for you.

I am,
Respectfully,
(Signed) R. B. OWENS,
Secretary.

RBO:S

THE FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
Philadelphia

MARCH 22, 1917.

Chevalier W. L. F. C. van Rappard,
Envoy Extraordinary and Minister
Plenipotentiary of Her Majesty,
the Queen of the Netherlands.

YOUR EXCELLENCY:

I have the honour to inform you that The Franklin Institute has awarded to Prof. Hendrik Antoon Lorentz, Professor of Mathematical Physics, University of Leiden, Leiden, Holland, The Franklin Medal, founded for the recognition of those workers in physical science or technology, without regard to country, whose efforts, in the opinion of the Institute, have done most to advance a knowledge of physical science or its applications.

The award is minuted as follows:

> "That The Franklin Medal be awarded to Hendrik Antoon Lorentz, President, Royal Academy of Sciences, Amsterdam, Professor of Theoretical and Mathematical Physics in the University of Leiden, in recognition of his researches which have so largely contributed to laying on a new foundation our knowledge of the nature of light and in developing our ideas concerning the ultimate constitution of matter."

The medal and accompanying certificate are being prepared, and I am requested, on behalf of our management, to extend to you a cordial invitation to come to the Institute on Wednesday, May 16, to receive this medal and certificate from our President, on behalf of your Government, for Professor Lorentz.

Two Franklin Medals have been struck this year, one going to Professor Lorentz, and one to Admiral D. W. Taylor, Chief Constructor and Chief of Bureau of Construction and Repair, United States Navy.

You and Admiral Taylor will be asked to be guests of honour at a dinner following the presentation ceremonies, which will probably occur at 4 P.M., but in this connection our President, Dr. Walton Clark, will communicate further with you.

I am
Your Excellency's very humble servant,
(Signed) R. B. OWENS,
Secretary.

RBO:S

WASHINGTON, 23 March, 1917.

KONINKLYK GEZANTSCHAP
DER NEDERLANDEN

No. 1333

MY DEAR MR. SECRETARY:

I am in receipt of your courteous note of the 22nd instant communicating to me the great honor which The Franklin Institute has bestowed upon my countryman, Professor Hendrik Antoon Lorentz, of Leiden, by awarding to him The Franklin Medal for his work in the field of physical science.

I shall consider it, my dear Mr. Secretary, a privilege to receive this medal and certificate on behalf of my Government for Professor Lorentz from the President of the Institute on Wednesday, May 16, in the Institute's Building.

Very sincerely yours,
(Signed) W. L. F. C. v. RAPPARD.

THE SECRETARY OF THE FRANKLIN INSTITUTE,
Philadelphia, Pa.

THE FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
Philadelphia

MARCH 13, 1917.

D. W. Taylor, Chief Constructor and
Chief of Bureau of Construction and
Repair, U. S. Navy,
Navy Department,
Washington, D. C.

SIR:

I have the honour to inform you that The Franklin Institute has awarded you The Franklin Medal, founded for the recognition of those workers in physical science or technology, without regard to country, whose efforts, in the opinion of the Institute, have done most to advance a knowledge of physical science or its applications. The award is minuted as follows:

> "That The Franklin Medal be awarded to David Watson Taylor, Chief Constructor and Chief of Bureau of Construction and Repair, U. S. Navy, in recognition of his fundamental contributions to the theory of ship resistance and screw propulsion, and of his signal success in the application of correct theory to the practical design of varied types of war vessels in the United States Navy."

The medal and accompanying certificate are being prepared, and I am requested, on behalf of our management, to extend to you a cordial invitation to come to the Institute on Wednesday, May 16, to receive this medal and certificate from our President.

I am,
Respectfully,
(Signed) R. B. OWENS,
Secretary.

RBO:S

BUREAU OF CONSTRUCTION AND REPAIR,
NAVY DEPARTMENT
Washington, D. C.

Dr. R. B. Owens, MARCH 16, 1917.
Secretary, The Franklin Institute,
Philadelphia, Pa.

SIR:

I have the honour to acknowledge the receipt of your communication of March 13, 1917, advising me that The Franklin Institute had made an award to me of The Franklin Medal.

Allow me to express my deep appreciation of the very great honor conferred upon me by the Institute through this award.

It gives me great pleasure to accept the very cordial invitation which you have extended to me, to come to the Institute on Wednesday, May 16, to receive this medal and certificate from your President.

I remain,

Very sincerely yours,
(Signed) D. W. TAYLOR,
Chief Constructor, U. S. N.

PROGRAMME OF MEETING, MAY 16, 1917.

Presentation of The Franklin Medal to His Excellency Chevalier VAN RAPPARD, on behalf of the Royal Netherlands Government, for HENDRIK ANTOON LORENTZ, Ph.D., F.R.S., President, Royal Academy of Sciences, Amsterdam; Professor of Mathematical Physics, University of Leiden.

Presentation of The Franklin Medal to DAVID WATSON TAYLOR, D.Eng., Chief Constructor, Chief of Bureau of Construction and Repair, United States Navy.

Address by Admiral David Watson Taylor, "The Science of Naval Architecture."

PRESENTATION OF THE FRANKLIN MEDAL TO DOCTORS HENDRIK ANTOON LORENTZ AND DAVID WATSON TAYLOR.

In calling the meeting to order the President of the Institute announced that the business of the meeting would be the annual presentation of the Institute's highest award, The Franklin Medal, in recognition of distinguished scientific and technical achievement, and recognized Dr. Harry F. Keller, who made the following statement relative to the work of Doctor Lorentz:

Mr. President: In the choice of the two eminent scientists who, in its opinion, should be recognized this year by the award of The Franklin Medal, the Committee on Science and the Arts was prompted by a desire to emphasize particularly two of the provisions in the deed of gift of the founder of the medal, Samuel Insull, Esq. They stipulate that this highest award within the gift of the Institute should be bestowed without regard to the nationality of the recipient, and that it should be available for the recognition of highest achievements both in pure science and in its applications. It should be noted, however, that when the committee submitted its report to the Institute the existence of a state of war between our country and the German Empire had not been declared by our Government, and that, in view of this fact, the committee could not have been influenced in its recommendations by any political considerations other than this: that, so long as this country remained neutral, these awards should go only to citizens of countries not actively engaged in the European conflict.

In these circumstances, it is most gratifying to us that the committee's action not only required no revision under the changed conditions, but that, on the contrary, it appears all the more felicitous because of them. For the medallist who represents the purely scientific side of physics is a native and citizen of the same friendly country as the only foreign savant upon whom this distinction has hitherto been conferred; while the other recipient of the medal is a man of pure American stock who has devoted his life to achievements of the first magnitude in connection with the defence of our country and the development of its navy.

The eminent scientists to whom we are about to pay this tribute both achieved their great successes very largely by virtue of their extraordinary command of higher mathematics, and, being myself but a tyro in the science of quantities, it is not without some trepidation, though with a vivid sense of the privilege accorded to me, that I venture upon a brief appreciation of their labors, and that I present to you, Mr. President, the distinguished guests of the Institute who are to accept the medals from your hands.

Under the title "Traité de la Lumière" the celebrated Dutch physicist and astronomer, Christian Huyghens, published in 1690, in the town of Leiden, one of the greatest classics of science, in which he propounded and developed the wave theory of light. For more than a century this hypothesis made little headway against the corpuscular theory enunciated by Huyghens' great contemporary, Sir Isaac Newton, but at the beginning of the nineteenth century the discoveries of Young and Fresnel paved the way for its general acceptance in a modified and extended form. In our own time, however, this conception that light consists in a wave motion of the ether has again been superseded by another, known as the electro-magnetic theory of light, first proposed by Clerk Maxwell, and our present ideas on the nature of light, and of electricity and radiant heat as well, have been given their present form by the master mind of another great physicist of Holland, whose work also was made known to the world from the town of Leiden.

It is to him that The Franklin Medal for highest achievements in physical science is awarded for this year. Like the lives of other great mathematicians and philosophers, the career of Hendrik Antoon Lorentz has been devoid of picturesque and dramatic incidents; its story is one of single-minded devotion to the advancement of knowledge in the still atmosphere of a small university town. The Who's Whos in Science, while presenting long lists of his achievements and publications, give but a few meagre data concerning his life. From these we gather that he was born July 18, 1853, at Arnheim, the capital of Gelderland, and that he received his university training at Leiden, where he took the degree of Doctor of Philosophy in 1875. After teaching a few years in the public evening school of his native town, he was called to the chair of Mathematical and Theoretical Physics in Leiden University in 1878. At the same time his no less eminent colleague, Prof. H. Kammerlingh Onnes, was elected to the professorship of Experimental Physics, and it is due to these two intellectual giants, working in harmony, and each one supplementing and fructifying the labors of the other, that this university has become one of the world's great centers of physical research. A great number of the noted physicists of this generation have received their training and inspiration from these men, and not a few of the great discoveries and achievements in physical science can be traced to their joint activities.

The investigations of H. A. Lorentz extend over practically all provinces of physical science, but, as has already been indicated, his most important achievements are in the fields of light and electricity, and in the study of the ultimate constitution of matter. He has published a long series of researches on optic phenomena under the most varied conditions, and it is chiefly to him that we owe the form in which the electro-magnetic theory has gained universal acceptance. His contributions on the structure of the elemental atoms and the nature of electrons rank with those of such investigators as J. J. Thompson and E. Rutherford, and his brilliant and satisfying explanation of the Zeeman effect led to most remarkable discoveries by American astronomers in connection with sun spots, which showed these to be electric cyclones, and thus opened up new fields to solar and stellar research.

His lucid discussion of the positive and negative electrons is still fresh in the memory of those of us who were present at the Franklin Bicentenary, held in this city in 1906, when he came here with his daughter to bring the greetings of the Dutch Academy of Sciences to the American Philosophical Society, and to deliver a course of lectures at Columbia University. Quite a number of books published by Professor Lorentz are recognized as the standard works on the subjects treated. He has been honored by the leading learned societies of the world by being elected an honorary or corresponding member. He is president of the Dutch Academy. In 1902 he was signally honored by the award of the Nobel Prize in Physics.

And now, Mr. President, this venerable Institute of ours delights in joining in this universal tribute to the vast achievements of the majestic intellect of Hendrik Antoon Lorentz. For reasons which require no explanation he cannot be with us to receive The Franklin Medal from your hands, but we are honored by the presence of the distinguished Ambassador of the Royal Netherlands Government who, as we so pleasantly remember, came here two years ago to accept, on behalf of his Government, The Franklin Medal that was then awarded to Professor H. Kammerlingh Onnes, and who will now be pleased to receive from you the medal for Professor Lorentz. I have the honor to present to you His Excellency, Chevalier W. L. F. C. van Rappard, Ambassador of the Royal Netherlands Government.

The President, in presenting The Franklin Medal to Chevalier van Rappard, said:

Your Excellency: For the second time within your term as Ambassador to the United States the work of a Netherlands scientist has commended itself to The Franklin Institute as worthy of the highest honor in the gift of the Institute. Therefore, for the second time, it is my pleasure and my honor to entrust to you The Franklin Medal for transmission, through the State Department of your gracious Queen, to one of her subjects, the medallist in this instance being Professor Hendrik Antoon Lorentz, President of the Royal Academy of Sciences of Amsterdam.

In accepting the medal for Doctor Lorentz, Chevalier van Rappard said:

Mr. President, Members of The Franklin Institute of the State of Pennsylvania, Ladies and Gentlemen: For the second time the great honor has been conferred upon me to accept, in the name of my Government, The Franklin Medal on behalf of one of my most distinguished countrymen. This fills me with joy and pride. It is most gratifying to me, as the representative of the Netherlands, to see in this new appreciation of the science and of the talents of a Hollander that it is not absolutely necessary to be a great power to produce to the world great men; that also a country, hardly the size of the state of Maryland, is able to prove by such men as Professor Lorentz and Professor Onnes that she deserves a prominent place among the nations of the earth, and that Holland has not been inferior to the larger nations in ideals and in her contributions to human progress and to civilization.

Though Napoleon called Holland a mere deposit of German mud vomited by the Rhine, and though Andrew Marvell, long before him, spoke of it as the offscouring of the British sand, adding that the people fished the land to shore, and though many others have waxed facetious over Holland's oddity, one poet characterizing the Netherlands as a land " Where people do not live, but go aboard," yet those who have studied her history concede that she has played as great a part in human affairs as countries to whom Nature was more kind. Her chief advantages were her disadvantages, for these made possible the survival of only the fittest.

This year you again honored a descendant of those old Hollanders, and by that selection you again showed to the scientific world that in science and learning my dear, small country holds its own, and that still now the Netherlands belong to the most inventive of all the nations of Europe as they were in the past, when they were inventive under the spur of necessity.

With your permission I deem it fitting to mention here a few of the Hollanders' many inventions. In the Netherlands originated the sawmill, the windmill, wood-engraving, oil painting, the printing of letters from wooden blocks, which preceded the movable type of the Germans; the thimble, spectacles, window glass, the use of the greenhouse in horticulture, the iron plow, counterpoint in music, the telescope and the microscope, upon the use of which all modern science is based; the mariner's compass, and the thermometer.

It was Christian Huyghens who, besides originating the theory of the vibration of light, was the first to apply the micrometer to the telescope; less known, but not less important, is the work of Stevinus, who, in 1586, by his book on "The Principles of Equilibrium," founded the Science of Statics, who introduced decimal fractions, and who predicted the world's adoption of decimal coinage, weights, and measures.

It is particularly gratifying to me that Professor Lorentz, upon whom you bestowed this year the greatest distinction you dispose of, belongs also to the University of Leiden. You all know how the University of Leiden originated: Preferring learning to "perpetual immunity" from taxes, the citizens founded and fostered what is perhaps the greatest of all modern universities, for no other institution has produced so many great men. On the roster of its professors and students are hundreds of lasting renown, among others: Scaliger, Vossius, Heinsius, Christian Huyghens, the great Grotius, Hooft, Rembrandt the painter, Lipsius, the philologist and historian; Boerhaave, the great physician; Drusus, the Orientalist; Gomarus and Arminius, the theologians, and hundreds of others.

In Leiden, too, were printed the Elzevirs and all books that could not get a hearing elsewhere. And it is an index to the education of the people and to the status of the country to learn that fifteen editions of the Old Testament and twenty-four of the New had been printed and published at Leiden before the first Bible was printed in England.

I hope you won't take it amiss nor consider me conceited because I have drawn for a moment your attention upon our oldest University and upon my brave little country. You have brought that upon yourselves by again, in the person of Professor Lorentz, as you did a few years ago in the person of Professor Onnes, distinguishing a countryman of mine and giving again a testimonial of the highest value to a modest worker of the Low Countries, who gives himself entirely to the science, and who surely will see in the great distinction offered to him by your institution not only a great reward for what he has done till now, but also a great encouragement to continue his successful work.

In the name of the Government of Her Majesty, my gracious Queen, I declare to accept, with the expression of Professor Lorentz's and of Holland's most sincere thanks, on behalf of my countryman, Professor Lorentz, of the University of Leiden, The Franklin Medal, and I express the hope that this renewed proof of esteem given by your great new country will lead to an (if possible) still closer bond with the small old country at the other side of the ocean.

In introducing Doctor Taylor, Doctor Keller said:

Mr. President: While this Institute derives very great satisfaction from its ability to fittingly recognize the lifework of a scientist like Professor Lorentz, it is no less gratifying to our membership to witness the presentation of The Franklin Medal to a compatriot who has to his credit so many achievements of the highest order in the application of physical science to our welfare and national defence. The career of this medallist must be a source of intense pride and an inspiration to every American; for his achievements are such as to place him in the foremost rank of naval engineers of any country and of any time.

He was born March 4, 1864, in Louisa County, Virginia, as a lineal descendant of distinguished soldiers and statesmen of the Revolutionary period. His early education and preparation for college he acquired by home instruction and study, entering the Randolph-Macon College in Virginia as a mere boy of thirteen. On completing the four-year course in this institution in 1884, he won an appointment as cadet engineer in the Naval Academy at Annapolis, attaining second place among 130 competitors from the country-at-large. He graduated in 1885 at the head of his class, and with the highest percentage of marks for the entire course ever attained by any graduate of the academy before or since that date. In the fall of the same year he was ordered to London to enter a three-year post-graduate course in naval architecture at the Royal Naval College at Greenwich. At the end of the first year he had made such a high record in scholarship that the Secretary of the Navy appointed him an assistant constructor with the rank of junior lieutenant, and upon the completion of the entire course he established a record for percentage of marks which has never been equalled by any graduate of the college, either before or since that time.

His career of constructive work he began as a member of the Corps of Naval Constructors of our Navy, in which position he greatly distinguished himself by solving a number of important problems in connection with the resistance and power of ships. The results of this work are recorded in numerous papers which he presented before the leading engineering societies of the world, and in two comprehensive treatises. The gold medal of the British Institute of Naval Architects was awarded to him for a paper entitled "On Ship-shaped Stream Forms," while another paper, under the title "The Theoretical and Practical Methods of Balancing Marine Engines," won for its author the first prize in a competition of the American Society of Naval Architects and Marine Engineers. His books on the "Resistance of Ships and Screw Propulsion" and on "The Speed and Power of Ships" have come to be universally recognized as the standard works upon these subjects.

But his most important contributions to the scientific side of naval architecture are based upon the work he conducted at the United States Experimental Model Basin, which he designed and constructed at Washington, D. C., in 1897, and of which he had charge until 1914. During this period of his life a surprisingly wide range of subjects engaged his attention, and many instances might be cited in illustration of his resourcefulness in formulating and experimentally attacking problems in subjects of which very little was known before. A case in point is his brilliant experimental researches on "The Interaction Due to Suction between Passing Vessels," a subject on which there was little or no reliable information, save a few observations on cases of damage to ships by unexplained collisions. By his brilliantly conceived and successfully conducted experiments he placed the subject on a scientific basis, and this work aroused such a widespread interest that, at the time of the trial in England of the celebrated case arising from the collision between the White Star liner *Olympic* with the British cruiser *Hawk,* he was invited, both by the British Government and the owners of the *Olympic,* to appear as an expert witness.

During the years he had charge of the Model Basin he by no means confined his attention to the theoretical aspects of naval architecture, but he was also the principal adviser to the Chief Constructor of the Navy on all matters pertaining to the design of every vessel of importance on the navy list. It was in this capacity that he conceived what is now known as the " American " or " centre-line " arrangement of gun turrets on the " Dreadnought " or " big-gun " type battleships built for the American navy, and which has since been adopted by every great Naval Power.

In December, 1914, he was appointed, by the President, Chief Constructor of the United States Navy, with the rank of Rear Admiral, and Chief of the Bureau of Construction and Repair. In this capacity he has been responsible for the design and building of the huge naval program provided for during the last two years.

The sparing intervals of leisure in his busy life he loves to spend on his country place in Virginia, where he successfully applies scientific principles to farming on a large scale.

Mr. President, at this time when our country's safety and success in the great war depend so largely upon a powerful and efficient navy I deem it a special honor and privilege to present to you as Franklin Medallist a man who has played a foremost part in its development, and who is conceded to be the greatest living naval architect and naval constructor, Admiral David Watson Taylor.

Before presenting the medal to Admiral Taylor, the President read the following message from the Honorable Josephus Daniels, Secretary of the Navy:

WESTERN UNION TELEGRAM

Dr. R. B. Owens,
Secretary, The Franklin Institute, Philadelphia, Pa.

I regret that official duties deny me the pleasure of being present today when The Franklin Institute awards The Franklin Medal to Admiral Taylor. No distinction has been awarded by any institution to a man who deserved it more. Admiral Taylor is not only an honor to the Navy, but has added lustre to American accomplishment in a field calling for the highest ability.

JOSEPHUS DANIELS.

DAVID WATSON TAYLOR

The President then said:

Admiral Taylor: I have the honor, in the name of The Franklin Institute, upon the recommendation of its Committee on Science and the Arts, and in recognition of your distinguished services to humanity, and particularly to your nation, rendered in the field of science, to present you The Franklin Medal and Diploma, the highest honor in the gift of the Institute.

After expressing his appreciation of the honor conferred upon him, Doctor Taylor read a paper entitled: "The Science of Naval Architecture" (see page 1).

Chemical Composition Versus Electrical Conductivity. C. G. FINK. (*General Electric Review,* vol. xx, No. 5, 363, May, 1917.)—Some years ago the author carried out a number of experiments on the electro-thermic production of ultramarine. Powdered mixtures of sodium sulphide, china clay, and carbon were interposed between carbon electrodes in a closed crucible furnace. It was observed at the time that in order to keep the electrical resistance and the temperature of the charge low enough to avoid decomposition of the ultramarine as soon as it was formed it was necessary to use very finely divided carbon, such as lampblack. With charges made up of powdered coke it was not possible to pass an appreciable current between the carbon electrodes up to potentials of 250 volts.

To obtain values of a more quantitative nature, a series of tests were made. Two substances were selected, the physical properties of one as divergent as possible from those of the other: a black metal powder, tungsten, and a white insulator powder, thoria. The advantages are that both tungsten and thoria will withstand very high temperatures and can therefore be made practically moisture-proof. The results showed, in general, that the electrical conductivity of a substance is primarily dependent upon the shape and the distribution of the fundamental grains or particles composing the substance, and, secondly, upon the presence or absence of thin films of secondary material enveloping these ultimate grains. On the basis of these conclusions we can account for the comparatively high conductivity of gels that contain but a trace of conducting material. We can also account for the marked difference in resistance of, say, two samples of commercial copper of identical chemical composition, depending upon whether the impurity, such as sulphur, is uniformly dissolved in the metal or whether it forms a film ("cement") of copper sulphide around pure granules of copper. The latter case is to be regarded, as Bancroft suggested, as an emulsification of copper in copper sulphide. The high resistance of these surface films composed of, say, sulphide or oxide or arsenide accounts for the high resistivity values of copper containing but a trace of one or more of these impurities.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

THE CALCULATION OF THE CONSTANTS OF PLANCK'S RADIATION EQUATION; AN EXTENSION OF THE THEORY OF LEAST SQUARES.[1]

By Harry M. Roeser.

[ABSTRACT.]

THE problem of computing from experimental data the constants, c_1 and c_2, of Planck's radiation equation for the distribution of energy in the spectrum of a black body is attacked by the method of least squares. The data were furnished by Dr. W. W. Coblentz and had been used to determine the constant c_2 by another method (*Bulletin Bureau of Standards*, 13, 1916, p. 474).

The observation equations were reduced by taking logarithms of both sides and assigning proper weights to the equations so transformed. The method of assigning weights is given in a general form that can be adapted to any scheme of transformation.

It is shown that the "two point" method (*Bulletin Bureau of Standards*, 13, 1916, p. 535) of determining c_2 may be made identical with the least square solution if all possible pairs of points are combined and a proper system of weights is applied to the separately computed values before taking the mean. This is suggested in T. W. Wright, "Adjustment of Observations," 1884, page 141. A short numerical example is given to show that by this system of weights being applied to an arbitrarily selected number of computed values the weighted mean approximates the least square value better than the simple mean.

THE LUMINOUS RADIATION FROM A BLACK BODY AND THE MECHANICAL EQUIVALENT OF LIGHT.[2]

By W. W. Coblentz and W. B. Emerson.

[ABSTRACT.]

THIS paper gives applications of the visibility of radiation of the average eye to radiation problems, including the luminous energy emitted by a black body at various temperatures, the

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* Communicated by the Director.

[1] Scientific Paper No. 204.

[2] Scientific Paper No. 305.

luminous efficiency, the Crova wave-length, and the mechanical equivalent of light.

The visibility curve of the average eye (125 observers) gives a mechanical equivalent of 1 lumen = 0.00161 watt of radiant energy of maximum visibility. Various other determinations give values varying from 0.00157 to 0.00160 watt.

The most reliable data now available indicate a value of 1 lumen = 0.0016 watt of radiant energy of maximum visibility; or 1 watt = 625 lumens = 49.8 candles of radiant energy of maximum luminous efficiency.

AN EXPERIMENTAL STUDY OF THE FAHY PERMEAMETER.[1]

By Charles W. Burrows and Raymond L. Sanford.

[ABSTRACT.]

This permeameter was developed during the course of an investigation at the Bureau of Standards on the magnetic-mechanical properties of steel. In order to ascertain the degree of accuracy attained, as well as its fitness for general laboratory use, a critical experimental study of the instrument in its present form has been made.

The instrument represents a distinct advance in the measurement of the magnetic characteristics of steel and other magnetic materials. In accuracy it far excels the direct-reading permeameters which have been rather commonly used both in this country and abroad. Normal induction measurements of solid bars show errors no greater than five per cent. of the magnetizing force required for a given induction. The consistency of its readings taken at different times on the same specimen is so close that comparative results on similar materials can be obtained to a much higher degree of precision. Commercial materials, however, are seldom uniform enough to warrant better precision than five per cent. Hysteresis measurements are accurate within the limits of commercial requirements and the uniformity of commercial materials.

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[1] Scientific Paper No. 206.

NOTE ON ELECTRICAL CONDUCTION IN METALS AT LOW TEMPERATURES.[1]

By Francis B. Silsbee.

[ABSTRACT.]

THE experiments at the University of Leiden at extremely low temperatures have shown that certain metals show an abnormally great electrical conductivity. It has also been discovered that if either the magnitude of the current flowing in the specimen, or the magnetic field in which the specimen may be placed, is increased above a certain critical value, then this abnormal conductivity disappears. In this paper it is pointed out that these two experimental facts are not independent, but that the phenomenon of critical current is a necessary consequence of the existence of a critical value of magnetic field. The relation between the two is that the critical value of the current is that at which the magnetic field due to the current itself is equal to the critical magnetic field. On account of the great experimental difficulties connected with work in this range of temperature, the quantitative data available for testing this relation are rather scanty as yet, but the data which are available are in satisfactory agreement with the theory.

GAS CALORIMETER TABLES.[2]

[ABSTRACT.]

THE numerous requests for a brief and concise set of operating directions for a gas calorimeter, and for a convenient set of correction tables, has resulted in the publication by the Bureau of Standards of Circular No. 65, "Gas Calorimeter Tables." This may be regarded as a supplement to Bureau Circular No. 48, "Standard Methods of Gas Testing." The correction tables are arranged in a sequence most convenient for use in connection with the proposed record sheet.

The record forms for calorimeter tests which are shown in the circular have been used for some time and found to be complete and convenient. It is hoped that these forms will be adopted wherever possible, so that there will be greater uniformity in operating methods and the records used. The Bureau is willing to loan the original plates for preparation of electrotypes for these blanks to any one desiring to print them.

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[1] Scientific Paper No. 207.

[2] Circular No. 65.

COMPARATIVE TESTS OF STITCHES AND SEAMS.[1]

By Walter S. Lewis.

[ABSTRACT.]

THIS work was undertaken with a view of determining the essential differences between seams produced by two methods of stitching by the sewing machines most extensively employed. Seams of the double-locked stitch and the shuttle stitch, sometimes called lock stitch, were tested to show their relative strength and other characteristics.

DOUBLE-LOCKED STITCH.

The double-locked stitch is produced without the use of a shuttle, and in the formation of a seam all threads are fed directly from original spools or bobbins without any rewinding. The under thread is called the looper thread and is guided into place by a small metal arm, containing an eye through which the thread passes. This arm works back and forth, forming one part of the stitch as the needle or upper thread works up and down through the fabric. Inasmuch as no shuttle is employed, there is no time lost in rewinding a bobbin or refilling a shuttle, which is necessary with the sewing machine commonly used in the household.

SHUTTLE STITCH.

The shuttle stitch is produced by the use of a shuttle which supplies the under thread while the upper thread passes through the needle. With this method of stitching the shuttle must be removed from the machine, from time to time, to refill the bobbin.

STRENGTH OF SEAMS.

Several kinds of fabric were stitched by each method and by using various combinations of thread sizes. The seams thus produced were tested to determine which method of stitching produces the stronger seam, greater stretch, etc. Various types of tensile strength test specimens were used, and it is believed that these gave a fair comparison of the strength of the two types of seams tested.

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[1] Technologic Paper No. 96.

EFFECT OF A BROKEN STITCHING THREAD.

Comparative tests were made with specimens in which the stitching thread was broken. It was found that the shuttle-stitch seam was weakened much more than the double-locked stitch, and the pulling out of the threads in the former stitch caused the seam to give way before the fabric was torn. This is objectionable, because the hole thus produced must be sewed up to prevent it becoming larger. With the double-locked stitched seam, however, a broken stitch does not produce a hole, as each loose end becomes securely locked and the seam remains as strong as it was originally.

Other tests were made to show the stretching qualities of the two kinds of stitching. The results of these tests show that the double-locked stitch is more elastic, stronger, and less likely to be injured by tension along the seam than the shuttle method of stitching.

The results of this investigation show that seams produced by the double-locked stitch are superior to the shuttle stitch. No attempt was made to compare the two types of stitching in other respects, such as production capacity of the two types of machines; cost of production, with special reference to consumption of time, thread, and fabric; deterioration due to wear, etc.

Acid-resisting Properties of Some Iron-silicon Alloys. O. L. Kowalke. (*Proceedings of the American Electrochemical Society*, May 2–5, 1917.)—Various acid-resisting alloys of commercial importance have been produced within recent years, and among these the iron-silicon alloys seem to give satisfactory service in many operations. Little information, however, seems to have been published on the acid-resisting properties of the iron-silicon alloys, and an investigation was undertaken to determine their resistance to several common acids.

Eighteen low-carbon iron-silicon alloys, containing 1.2 to 19.8 per cent. of silicon, were immersed from periods of 51 hours to 29 days in 10 per cent. solutions of sulphuric, hydrochloric, nitric, acetic, and citric acids, and the losses determined. With a few irregularities the resistance to acid attack was a minimum at 1.2 to 3.3 per cent. silicon, and a maximum at 16 to 18 per cent. The latter alloys are very hard and brittle. Attempts are being made to find an addition element which will decrease these undesirable qualities without impairing the resistance to acids.

Automobile Headlighting. S. C. ROGERS. (*Transactions of the Illuminating Engineering Society*, vol. xii, No. 3, p. 158, April 30, 1917.)—Judging by the generally unsatisfactory results which have been obtained up to the present time in endeavoring to secure adequate road lighting without presenting intolerable glare to persons facing the headlamp, the practical problem presented by the regulation of the use of high-power headlamps is apparently an extremely difficult one. Only by the close application of a thorough knowledge of the processes of vision and the requirements of headlighting may a satisfactory compromise be effected.

If it were possible to secure a point light source, a true paraboloid would project a cylindrical beam of the same diameter as the reflector and consisting of wholly parallel rays, provided that the light source were at the focus. If this point light source were placed behind the focus, a conical beam consisting of entirely divergent rays would result. If this point light source were moved in front of the focus, an " hour glass " beam consisting of converging rays would result. Likewise, if the light source were moved in a vertical plane perpendicular to the axis of the paraboloid at its focus, the beam would be lowered or raised, depending upon whether the light source were raised or lowered. Light sources have physical dimensions, however, and the spread of the beam will depend upon the size and shape of light source used and also upon the location of the latter with respect to the focus of the paraboloid.

Ability to detect persons, objects, etc., at a considerable distance in front of the car depends upon various factors. The high candlepowers used are sufficient, but the characteristics of road surfaces and the adaptability to darkness of the eye must be considered. It has been commonly asserted by many that a beam of yellow light will penetrate fog or dust better and will produce less glare than the same intensity beam of white light. It should be borne in mind that yellow light for headlamp work is not the same yellow light for general illumination. As a result of many headlamp tests, no reduction in glare has been found, except that directly traceable to the lesser intensity of the headlamp due to the absorption of the glass, nor any better penetration of fog, dust, or smoke. The only advantage that could be found was a reduction of the diffractive halation or back glare when driving through a rainstorm or heavy fog. On the other hand, halation around an opposing headlamp usually results in reducing the contrast glare. Over two thousand methods have been developed for overcoming the dazzling rays or glare. Among these commonly seen at present are: parabolic reflectors with devices placed in the path of the reflected light, parabolic reflectors with devices placed between light source and reflector, special light sources, and reflectors of special designs and shapes.

NOTES FROM RESEARCH DIVISION, ELECTRICAL ENGINEERING DEPARTMENT, MASSACHUSETTS INSTITUTE OF TECHNOLOGY.*

CONVECTION OF HEAT FROM SMALL WIRES IN WATER.

THE laws of the forced convection of heat from small wires carrying a steady electric current and moving transversely through air have been studied at some length.[1] A research into the case of small wires moving transversely in water was carried out by Messrs. Harold Worthington and C. B. Malone, Jr., as a thesis towards the S.B. degree, at the Massachusetts Institute of Technology, in 1915, under the direction of the Electrical Engineering Research Division. The results obtained are here briefly summarized.

The test wire was of platinum, No. 30 A. W. G. (0.256 mm. diameter), supported in a vertical frame holder. The latter was carried on the end of a motor-driven rotating arm in such a manner that the test wire was dragged through the water of a large tank, in a direction transverse to its length, at an adjustable velocity, and at a constant depth of immersion. The vertical frame was of steel, 41 cm. high, and designed so as to grip the test wire tightly, and to keep the latter vertically stretched, while stirring up the water as little as possible in the path of the wire's motion. The test wire was about 20 cm. long, and was connected by the grips of the holder to a storage battery through a controlling resistance and ammeter. In this way the current I, through the test wire, could be carried up to 17 ampères, under adjustable control. Pressure wires, fastened to the test wire, and 12.8 cm. apart, were led to a voltmeter, so as to show the drop of potential V in this working portion of the test wire. The product VI of the observed voltage and current gave the power dissipated by the wire, in watts, and this, divided by 12.8, gave the linear power dissipation in watts per linear centimetre of the test wire. The ratio V/I also indicated the working resistance of the 12.8 cm. of wire, and from this the mean temperature of the test wire became known.

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* Communicated by the Director.

[1] JOURNAL OF THE FRANKLIN INSTITUTE, June, 1917, p. 783.

It was found that the linear power P, dissipated from the test wire convectively, as the wire was hauled around in the water tank, was proportional to the temperature difference θ between the wire and the mass of the water, *i.e.*, to the temperature elevation of the wire, for velocities above 6 cm. per second. At velocities lower than this, the proportionality appeared to fail, perhaps because of irregular convection in the water due to liquid eddies.

The forced convection, for a given temperature elevation θ° C. of the wire, varied exponentially with the velocity V of the wire's transverse motion. At temperature elevations not exceeding 23° C., the linear dissipation P varied as the square root of the velocity, or as $V^{1/2}$. At higher temperature elevations, the exponent appeared to fall off, according to an empirical relation: exponent $= 0.55 - 0.003\theta$. The reason for this falling off in the exponent at higher values of θ is not known. It will be noted, however, that the activity in watts per square centimetre of wire surface becomes surprisingly large as θ is increased.

Within the limitations above indicated, the linear dissipation was found to follow the relation

$$P = 0.031\,\theta\,\sqrt{V} \text{ watts per linear centimetre} \quad (1)$$

where θ is the temperature elevation and V is the velocity of the wire's motion in centimetres per second, taking into account a certain experimental virtual velocity $v_0 = 1.15$ when the wire is at rest, and explainable as a velocity of free convection; that is,

$$V = v + 1.15 \text{ centimetres per second} \quad (2),$$

v being the true velocity of the wire through the water.

The total range of velocities v experimented with was from 0 to 16 cm. per second. It was not convenient to carry the velocity to higher values than 16 cm. per second, because of the stresses brought on the test wire and of the disturbances set up in the liquid. The dissipation for $\theta = 30$° C., and $v = 14.85$, or $V = 16$ cm. per second, would be, by (1), 3.7 watts per linear centimetre. This corresponds to 46 watts per square centimetre of test-wire surface.

In all of the later tests filtered tap-water from the Boston City mains was used. It was found that the surface cœfficient

0.031, in (1), could not be depended upon to keep constant for more than a few minutes at a time unless the wire's surface was cleansed by wiping it. A transparent superficial layer of dirt seems to form rapidly on the heated wire, and this causes the linear dissipation to diminish. Consequently any attempt to use the device for measuring the velocity of such water, passing the wire, would seem to call for some means of cleansing the wire at short, regular intervals.

It is interesting to note that the linear dissipation from a thin platinum wire in water, as above described, is more than one hundred times greater than that from a thin copper wire of the same diameter moving in air, at the same velocity and temperature elevation.

The Vosmaer Phenomenon. W. C. MOORE. (*Proceedings of the American Electrochemical Society,* May 2–5, 1917.)—A number of years ago a patent was issued to A. Vosmaer, of Haarlem, Holland (English patent, No. 21,887, 1899), for the production of light by means of a discharge between nickel wires serving as the secondary terminals of an induction coil. The phenomena involved were described by Vosmaer in *Metallurgical and Chemical Engineering* for June, 1914. In brief, when the wires used are of the correct size for the induction coil to which they are connected, and the distance between the ends of the wires is properly adjusted, the cathode wire fuses at the end, forming a small globule which glows with high intrinsic brilliancy.

Experiments made in the Research Laboratory of the National Carbon Company, Cleveland, Ohio, using a coil giving a normal spark of three inches, showed that (1) on turning on the current the cathode becomes intensely hot at its extreme end, and soon melts; (2) that the surface tension of the molten nickel is sufficiently great to draw the molten material up into a ball; (3) that while (1) and (2) are taking place, the outer portion of the fused mass becomes oxidized. This oxide adheres very firmly to the nickel, as it apparently has a higher melting-point than nickel, the nickel is protected from further attack and so is not consumed, and an equilibrium temperature is therefore soon reached. The fact that the ball, when the energy is liberated, is much larger than the wire, and the heat of conductivity decreases very rapidly with the temperature, causes this equilibrium temperature to attain a high value. The high emissivity of the nickel-oxide layer explains the high intrinsic brilliancy of the little ball.

New Alloys to Replace Platinum. F. A. FAHRENWALD. (*The Journal of Industrial and Engineering Chemistry*, vol. 9, No. 6, p. 590, June, 1917.)—The present phenomenal activities in chemical research and manufacturing enterprises have resulted in a continually increasing consumption of platinum, while statistics show that the world's production has been on the decline. At the present time an actual scarcity of the metal is of greater importance than its consequent high cost. The development of materials to take the place of platinum in many of its applications has consequently become not so much a matter of economic desire as one of actual necessity.

At the present time, when molecules, atoms, and electrons are a matter of fruitful study, the production of alloys of special properties is no longer the result of discovery, as in the days of the alchemist, and advances are now made by a study of the relation of the general properties of an alloy to the nature of its constituents. The relationship of the elements, best revealed by some form of the periodic table, showed that the general properties of platinum were possessed by no other metals except those adjacent to it in the table. The surrounding elements are iridium, rhodinium, palladium, silver, and gold. All metals outside of this region are affected by common reagents and gases, and without exception are not stable at elevated temperatures in normal atmospheres. Considering each of these in turn, it was found that not one is suited as a general substitute for platinum. The possibilities being limited to the small group indicated, it was necessary to combine these included metals in such a manner as to eliminate or neutralize undesirable features, and to develop those which were necessary. Among these, only gold and palladium were found available as the permissible *chief* components of an alloy having nearly the general properties of platinum.

A detailed investigation of alloys of these metals has resulted in materials which for many practical purposes cannot be distinguished from platinum. The name "rhotanium" has been applied to this series of alloys. Exhaustive tests have shown that most of the uses for which platinum has heretofore been considered indispensable can be filled by one of these gold-palladium alloys, thus freeing platinum for those remaining applications where no other material can be employed. The extent to which platinum may be replaced in this manner is limited by the amount of palladium available, and when it is considered that these alloys contain from 90 to 60 per cent. of gold it is evident that the effective supply of platinum may thus be increased by many thousand ounces.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

THE VOLATILE REDUCING SUBSTANCE IN CIDER VINEGAR.[1]

By R. W. Balcom.

[ABSTRACT.]

A HISTORICAL discussion is followed by experimental results which include details of the preparation and purification of the phenylosazone obtained from the distillate from cider vinegar. Such distillates contain a reducing substance which reduces Fehling's solution at room temperature. The melting-point of the phenylosazone and the amount of nitrogen it contained indicated that it was diacetyl phenylosazone. Diacetyl (CH_3–CO–CO–CH_3) and acetylmethylcarbinol (CH_3–CHOH–CO–CH_3), the two substances from which this osazone might be formed, were prepared and the behavior of dilute solutions of these two substances was compared with that of the cider vinegar distillate. It is shown that the reducing substance in the cider vinegar distillate is largely, if not wholly, acetylmethylcarbinol. This substance is not formed during the distillation of the vinegar. It is present as such in the vinegar and appears to be a normal constituent of cider vinegar.

SOME PROTEINS FROM THE JACK BEAN (CANAVALIA ENSIFORMIS).*

By D. Breese Jones and Carl O. Johns.

From the Protein Investigation Laboratory, Bureau of Chemistry,
Department of Agriculture, Washington, D.C.

[ABSTRACT.]

Two globulins, *canavalin* and *concanavalin,* and an albumin have been isolated from the jack bean. The air-dried jack bean meal contained 23 per cent. of protein, 15 per cent. of which is extracted from the meal by distilled water. A two per cent. sodium chloride solution extracted 18.5 per cent., and a 0.2 per cent. potassium hydroxide solution extracted nearly all of the

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* Communicated by the Chief of the Bureau.

[1] *J. Am. Chem. Soc.*, 39, 309–315 (February, 1917).

protein, or 22.3 per cent. By mixing the meal with three times its weight of 10 per cent. sodium chloride solution, and this mixture ground in a mill to break up the cells, 20.5 per cent. of protein was extracted (N × 6.25). Dialysis of salt extracts of the jack bean against distilled water yielded about 10 per cent. of pure, dry globulin, based on the weight of the meal used. The globulin was so soluble in salt solutions that it could not be precipitated by diluting these solutions with water. After the globulins had been removed, about 1.5 per cent. of an albumin was isolated as a flocculent coagulum from the dialysate by heating the latter to 75 to 80°. The globulin of the jack bean is not identical with phaseolin, isolated by Osborne from the kidney bean (*Phaseolus vulgaris*). Concanavalin, the globulin present in the jack bean in the smaller amount, and which is the less soluble, was precipitated from a one per cent. salt extract of the meal by adding ammonium sulphate to 0.6 of saturation. The precipitate was filtered off, redissolved in water, and dialyzed until free from sulphates. Canavalin was obtained by making the filtrate from the concanavalin completely saturated with ammonium sulphate. The chief difference between canavalin and concanavalin lies in their sulphur content; namely, 0.48 and 1.10 per cent. respectively. It is evident, from the analyses of these two globulins, that only a small amount of concanavalin can be present in the mixture of globulins obtained by dialysis, since the sulphur content of canavalin and the mixture of globulins are practically the same. Canavalin contains 3.17 per cent. of basic nitrogen. The albumin, which contains 3.73 per cent. of basic nitrogen, resembles the legumelins which have been described by Osborne and his co-workers.

THE PROTEINS OF THE PEANUT (ARACHIS HYPOGÆA).[1]

By Carl O. Johns and D. Breese Jones.

From the Protein Investigation Laboratory, Bureau of Chemistry,
Department of Agriculture, Washington, D. C.

[ABSTRACT.]

THE recent increase in the production of peanuts in the United States has stimulated a special interest in the peanut from an economic standpoint. The proteins of the peanut have received but little attention. The only published experiments seem to be those described by Ritthausen in a paper which appeared in 1880. The present investigation has shown that the proteins of the peanut consist chiefly of two globulins, *arachin and conarachin.* A small amount of albumin has also been isolated. The investigations were carried out on oil-free peanut meal obtained by pressing out most of the oil from raw Virginia peanuts by means of an Anderson expeller. The resulting press cake was then ground to a fine meal and the residual oil removed by extraction with petroleum ether. This meal contained 18 per cent. of nitrogen, equivalent to 45 per cent. of protein (N × 5.5). By extracting the meal with 10 per cent. sodium chloride solution, 32 per cent. protein, based on the weight of meal used, is dissolved at room temperature, 78 per cent. of which was actually isolated in pure form by diluting the salt extract with five to six volumes of distilled water, or by saturating with carbon dioxide. The same globulins were also obtained by dialysis of the salt solution. Arachin and conarachin were isolated by means of fractional precipitation of the protein extracted by salt solution.

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[1] *The Journal of Biological Chemistry*, vol. 28, 77 (1916)

Arachin, which represents the greater part of the total globulins, is the less soluble of the two, and is precipitated when in 10 per cent. salt solution by adding ammonium sulphate to 0.2 of saturation. After filtering off the arachin, conarachin can be obtained by dialysis, or by saturating the filtrate with ammonium sulphate. The greatest difference between these two globulins is in percentage of sulphur; namely, 0.40 and 1.09 per cent. respectively. Another striking difference is shown by the figures representing the distribution of nitrogen, particularly in the percentage of basic nitrogen, being 4.96 and 6.55 per cent. respectively. The percentage of basic nitrogen in the mixture of these globulins is also high, being 5.23 per cent. So far as known, conarachin contains more basic nitrogen than any other seed globulin yet examined. From the results obtained it seems probable that peanut press cake will prove to be highly effective in supplementing food products made from cereals and other seeds whose proteins are deficient in the basic amino-acids.

KAFIRIN, AN ALCOHOL-SOLUBLE PROTEIN FROM KAFIR (ANDROPOGON SORGHUM).[1]

By Carl O. Johns and J. F. Brewster.

From the Protein Investigation Laboratory, Bureau of Chemistry
Department of Agriculture, Washington, D. C.

[ABSTRACT.]

Hitherto no study has been reported on the proteins of kafir. The seeds used in this investigation were grown in Kansas, and were of the variety known as dwarf kafir. The ground seeds contained 11.7 per cent. of protein (N × 6.25), 7.9 per cent. of which was extracted from the meal by boiling 60 per cent. alcohol. There was isolated, by the use of alcohol ranging from 60 to 70 per cent., 5.2 per cent. of the pure protein, *kafirin*. In its ultimate composition kafirin closely resembles zein from maize. While zein is very soluble in 70 per cent. alcohol at all temperatures, kafirin requires a large quantity of the same strength of alcohol to effect solution. Kafirin is much more soluble in hot than in cold alcohol, and even rather dilute solutions will give a jelly on cooling. On this account it was necessary to use large volumes of alcohol, and to filter the extracts while hot. Kafirin coagulates easily, while an alcohol solution of zein does not coagulate when heated. Kafirin differs conspicuously from zein in the percentage of amide and basic nitrogen, being 3.46, 2.97 and 1.04 and 0.49 per cent. respectively. A further difference exists between kafirin and zein in the proportion of the diamino acids which these proteins yield. Kafirin contains lysine and tryptophane, both of which are lacking in zein, and which are necessary for animal nutrition.

D-MANNOKETOHEPTOSE: A NEW SUGAR FROM THE AVOCADO.[2]

By F. B. LaForge.

[ABSTRACT.]

The ripe fruit of *Persea gratissima* contains a ketose of seven carbon atoms which was isolated in the crystalline condition and found to be d-mannoketoheptose. Its formula was established by analysis of its bromphenyl hydrazon and phenyl osazon and by a comparison of the latter derivative with the osazon of mannoaldoheptose; also by the fact that it yielded the two epimeric mannoheptits on reduction with sodium amalgam. The melting-point of the new sugar was 152° and its specific rotation + 29°. It was not fermentable with yeast and was not changed by bromine in aqueous solution. This is the first heptose to be found in nature.

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[1] *Journal of Biological Chemistry*, vol. 28, 59 (1916).

[2] *Journal of Biological Chemistry*, vol. 28, 2 (January, 1917).

THE FRANKLIN INSTITUTE

(*Proceedings of the Special Meeting held Monday, June 25, 1917.*)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 25, 1917.

VICE-PRESIDENT COLEMAN SELLERS, JR., *in the Chair.*

The Chairman announced that the meeting was called for the purpose of transferring certain property devised to the Institute by the late William H. Wahl to the Institute's Board of Trustees and called upon Mr. Louis E. Levy to present the necessary resolution.

Mr. Levy then offered the following resolution:

"*Resolved*, That the title to premises 1806 Harlan Street, in the City of Philadelphia, being a part of the devise to The Franklin Institute for the Promotion of the Mechanic Arts under the will of William H. Wahl, deceased, and known as the 'John H. Wahl Fund,' be conveyed to the Trustees of The Franklin Institute in accordance with Article I, Section 1, of the By-Laws of the Institute, and that the President and Secretary be, and they are, hereby authorized and directed to execute the deed for the same."

After being duly seconded it was passed unanimously.

Adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of the Stated Meeting held Wednesday, June 6, 1917.*)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 6, 1917.

MR. WM. CHATTIN WETHERILL *in the Chair.*

The following report was presented for first reading:

No. 2694.—Lewis Machine Gun.

The following report was presented for final action.

No. 2687.—Brinell Meter. Recommended that Edward Longstreth Medals of Merit be awarded to Albert Ringland and Frank H. Schoenfuss, of Philadelphia, Pa., for their joint invention of this device.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, June* 13, 1917.)

RESIDENT.

MR. EDWARD J. BRADY, Engineering Research, The United Gas Improvement Company, 3101 Passyunk Avenue, Philadelphia, Pa.

MR. WALTER F. HAGER, JR., Manufacturer, Secretary and Treasurer, Keystone Screw Company, Seventeenth and Lehigh Avenue, Philadelphia, Pa.

NON-RESIDENT.

DR. RAIMUNDO CABRERA, Hotel Martinique, New York City, N. Y.

CHANGES OF ADDRESS.

MR. JOHN W. BRASSINGTON, 251 Oak Street, Holyoke, Mass.
MR. JOHN A. CAPP, 62 Bedford Road, Schenectady, N. Y.
DR. DAVID T. DAY, 715 N. Nineteenth Street, N. W. Washington, D. C.
MR. S. L. HAYES, West Point, Ga.
MR. C. P. LANDRETH, Electrolytic Purification Company, southwest corner Fifteenth Street and Lehigh Avenue, Philadelphia, Pa.
MR. C. L. MCILVAINE, 1925 North Second Street, Harrisburg, Pa.
MR. ROBERT S. REDFIELD, Barnstable, Mass.
MR. W. H. SHARP, 1811 Chestnut Street, Philadelphia, Pa.
MR. VICTOR W. ZILEN, Route No. 1, Box 139, Chattanooga, Tenn.

NECROLOGY.

Mr. G. W. Creighton, General Superintendent. Eastern Pennsylvania Division, Pennsylvania Railroad Company, Altoona, Pa.

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BOOK NOTICES.

PRELIMINARY MATHEMATICS, by Prof. F. E. Austin, B.S., E.E., Hanover, N. H. Published by the Author, 1917. IV + 169 pages. 4½ x 7½ inches. Price, $1.20.

The vocational or trade school student generally desires to abbreviate as far as possible the highly essential mathematical preparation prescribed as a prerequisite to the pursuit of the professional subjects of his course of study. As many such courses are conducted, there is scarcely any valid reason why this preparation should not be quite brief, in keeping with the elementary, but none the less practical, character of subsequent study. Moreover, the students in these special courses are often making their first acquaintance with mathematics, and a brief course covering considerable ground is an efficient means of giving a quick insight into its practical application and a stimulating method of inducing further study.

Preliminary mathematics is designed on this plan and covers the elements of arithmetic and algebra usually taught in the lower schools. In accordance with modern ideas, the two subjects are developed together, except in the opening chapters on fundamental notions of number and arithmetic operations, but throughout all succeeding presentations the relationship between numerical and algebraic operation is kept in sight.

Modern text-books on algebra make free use of graphs to visualize in a convincing manner the meaning of positive, negative, and imaginary quantities, and variables and functions. For some reason the author appears to have studiously avoided such diagrams. Imaginary quantities, however, are not mentioned. It is perhaps difficult to include in an abbreviated text everything that may seem needful to the varied types of users, and omissions of matter to meet particular requirements are inevitable. For instance, among others, an explanation of maxima and minima of second-degree functions would be exceedingly useful to many users. The book contains a large number of problems and an unusually large number of them worked out in detail, a feature of value to the student depending wholly on his own resources. The addition at the end of the volume of several college entrance examination papers with their solutions supplies a satisfying test of progress.

LUCIEN E. PICOLET.

THE METHOD OF ENZYME ACTION, by James Beatty, M.A., M.D., D.P.H., with an introduction by Professor Starling, M.D., Sc.D., F.R.S. Philadelphia. P. Blakiston's Son and Company, 1917. 138 pages and index, 8vo. Price, $1.75 net.

This work, written and printed in England, is an interesting example of how the scientists of that country, even in the storm and stress of a struggle greater than any that it has had to encounter since the days of the Armada, can yet find opportunity to discuss the most intricate problems, for the topic covered by the book is one of the most complex and difficult of all physical sciences, withal among the most important. The book reflects vividly however, the actual situation, for Professor Starling, who writes the introductory, is now Lieutenant-Colonel Starling, and dates his contribution from Salonika in January of this year. The world has long been familiar with two letters written to the people of that region; here is a very different type of letter written from that region and marking a great change.

The scope and general character of the book can be briefly set forth by a quotation from Professor Starling's introductory:

"Life can be regarded as a development in the presence of the two essentials, air and water, probably under the influence of the energy of the sun's rays. Since the majority of vital processes are associated with some form of ferment action, which in turn is always connected with the mobilization and shifting of HO and H ions, life itself may be regarded as the dynamical history of water."

The essay is an attempt to explain this mobilization. Space does not permit the setting forth of the manner and method in which the author proceeds with his task. The work is an interesting and useful addition to the literature of an important and difficult phase of biologic chemistry.

HENRY LEFFMANN.

PUBLICATIONS RECEIVED.

Shop Expense, Analysis, and Control, by Nicholas Thiel Ficker, consulting industrial engineer and lecturer on factory engineering and cost production at New York University, School of Commerce, Accounts, and Finance. 236 pages, plates, tables, 8vo. New York, Engineering Magazine Company, 1917. Price, $3.

Principles of Agricultural Chemistry, by G. S. Fraps, Ph.D., chemist, Texas Experiment Station, Agricultural and Mechanical College of Texas; state chemist. 501 pages, illustrations, 8vo. Easton, Penna., The Chemical Publishing Company, 1917. Price, $4.50.

The Microscope: An Introduction to Microscopic Methods and Histology, by Simon Henry Gage, Professor of Histology and Embryology, Emeritus in Cornell University. Twelfth edition, rewritten. 472 pages, illustrations, 8vo. Ithaca, N. Y., Comstock Publishing Company, 1917. Price, $3.

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CURRENT TOPICS

Development of the Coherer. E. C. GREEN. (*General Electric Review*, vol. xx, No. 5, May, 1917.)—The electric wave detecting device, first known as the Branly tube and later as a coherer, has been the subject of much research. Many experimenters in past years noticed that a number of metals, when powdered, were practically non-conductors when a small electromotive force was impressed on the loosely-compressed particles, while they became good conductors when a high electromotive force was applied. This knowledge can be traced as far back as 1835 to Monk of Rosenschoeld, who described the permanent increase in conductivity of a mixture of tin filings, carbon, and other conductors caused by the discharge through them from a Leyden jar. At various subsequent intervals the subject was further studied by C. Varley, S. A. Varley, Prof. D. E. Hughes, and Prof. T. Colzecchi-Onesti. Hughes, while engaged in research work on the microphone, seems to have discovered the important fact that zinc and silver filings placed loosely in a tube of glass were sensitive to electric sparks at a distance, as indicated by their sudden change in resistance.

In 1890, Prof. E. Branly, of Paris, published an account of a very comprehensive series of observations on the same subject that confirmed the work of previous observers and added a great deal of new information. While Professor Hughes seems to have discovered that loose masses of powdered conductors are sensitive to electric sparks at a distance, it remained for Professor Branly to make conclusive observations and thoroughly demonstrate this fact. Branly's work did not secure the notice it deserved until 1892, when Dr. Dawson Turner described Branly's experiments and his own additions to them. Up to June, 1894, when Sir Oliver Lodge described the Branly tube in a lecture before the Royal Institution and first gave it the name "Coherer," it was found to be a very capricious instrument; in instances highly sensitive to electric sparks, and then, all conditions being apparently the same, it became far less sensitive. The metals forming the most reliable coherers were iron, steel, copper, brass, and zinc, while the noble metals were much less reliable.

The man who really made the coherer famous, Guglielmo Marconi, began his work in Italy in 1894, and devoted his attention to the development of the Branly coherer. He made a systematic study of various coherer materials and selected for his work a mixture of 95 per cent. nickel and 5 per cent. silver filings carefully sifted to the same degree of fineness. He succeeded in producing a much more sensitive and reliable electric wave detecting device than had previously been designed. Marconi then proceeded to work out devices for employing his improved coherer as a relay upon a relay in a telegraphic outfit for receiving wireless messages. This last application caused world-wide interest in the coherer, and numerous experimenters began work upon it. Decoherence was produced in the metallic filings coherer by tapping, slowly revolving the tube. T. Tomasina was the first to use magnetic means directly for producing decoherence. He placed an electromagnet over the tube and in series with the coherer so that when it became sensitive the magnet was energized and lifted the granules to the top of the tube, thus producing decoherence. This method has been applied to a coherer developed by the General Electric Company, to be used in connection with discharge alarms for lightning arresters, high-frequency alarms, etc.

The New Military Rifle. A. B. BOWERS. (*Scientific American,* vol. cxvi, No. 19, p. 474, May 12, 1917.)—The regular army rifle, while in most respects an admirable weapon, is, in the opinion of many competent observers, open to grave objections on more than one ground. In the first place, the trigger by which the rifle is discharged is located below the stock, between narrow, open-sided guards, which are far from sufficient protection. Moreover, the manner of discharge, by pressure of the forefinger on the trigger, produces in many cases a sidewise and downward movement of the whole barrel sufficient materially to affect accuracy of aim. A far greater measure of inaccuracy in shooting is caused by the short distance between the sights. The back-sight is too far forward—from 12 to 18 inches from the eye. This defect cannot, however, be remedied off-hand, for, with the open back-sight used, this distance is necessary for accurate focussing of the two sights upon the target. Again, many users of rifles carry them at full cock so that they may be ready for instant use by releasing a locking device. Finally, in cold weather the gloved finger is too stiff to manipulate with safety the trigger now in use.

A Brooklyn inventor claims to have eliminated these various defects in a new gun recently patented. He has substituted for the old projecting finger-trigger under the stock a thumb-trigger above the stock. In operation it is only necessary to tighten the grip of the hand slightly in order to work this trigger; and at rest it is possible to guard it by a five-sided guard. A long-sighting range has been obtained, without any of the disadvantages enumerated, by attaching a peep-sight to the firing pin. In this way a broad base is obtained sliding in closely-fitting guards that preserve the alignment. Not only does this give the desired long-sighting range, but, bringing the back-sight to within four inches of the eye, it permits the use of a peep-sight small enough to insure accurate aim. The conflict between cocking and locking is automatically eliminated, for the base of the peep-sight so completely covers the thumb-trigger, when the gun is at cock, that the necessity for locking is wholly removed. Finally, the motion by which the discharge is accomplished is such a simple one that it can be made without the slightest difficulty, regardless whether the hand be bare or gloved.

Industrial Lifting Magnets. J. VICHNIAK. (*Le Genie Civil*, vol. lxx, No. 16, p. 253, April 21, 1917.)—The application of electromagnets to replace the familiar crane hook in handling iron and steel materials has proved of great value in materially reducing the labor entailed in moving about such material in the course of manufacture. Although the principle of the lifting magnet is very simple, it was only after much experimenting that a practical design was evolved adapted to the rugged requirements of rapid handling. The calculation of lifting power for materials with plane surfaces is not complicated, as the total flux and strength can be easily computed. When, however, objects of irregular shape are dealt with, it is only by tentative methods that the best proportions of the magnet can be found for a given class of material.

The lifting magnet is particularly useful for material not easily shackled, such as chips from machine tools, various structural discarded odds and ends, and also to material of regular shape of moderate weight. One unique application is in handling hot billets. These pieces, difficult to attach to the ordinary crane hook when hot, are readily raised and removed by the magnet. Special water-cooled magnets are empoyed for this service. It is well understood that the capacity depends upon the proximity of the piece to be lifted to the pole face. To increase the capacity when lifting irregular pieces, the Couffinal works at Saint-Etienne have designed a magnet with subdivided vertically movable pole faces. These subdivided faces, by their vertical movement, conform to the irregularities of the pieces lifted and prevent lateral motion, as well as increase the lifting capacity. Another special form of magnet for lifting a bundle of rods or other long pieces is provided with a linkage, somewhat after the manner of a clam-shell dredge bucket, operating arms that embrace the load held by the magnet. Once in place, the magnet is deënergized and the load is transferred to the arms, thus economizing current.

Testing Automobile Engines Electrically. ANON. (*Electrical World*, vol. 69, No. 12, p. 557, March 24, 1917.)—The use of the generator for engine testing is in itself an old device, yet there is much of novelty in the technical applications of this famliar process in the testing-room of the Toledo plant of the Willys-Overland Company. The first steps in the testing process are to mount the engine on the testing block and drive the engine at 500 r. p. m., using the generator as a motor. This overloads the motor by some 300 per cent. for a very brief period, perhaps one to three minutes, at the end of which time the friction load drops to normal. Then follows a half hour's run at the same speed, with a further decrease of load to about 20 per cent. its full value. At this point the speed is increased to 700 or 800 r. p. m., at which it is kept for an hour to an hour and a half, until the engine is fairly down to its proper friction load. The operation is then reversed, the engine driving the electric machine as a generator and delivering energy to the line. Next it is throttled, for half an hour to an hour, to about half load on the generator; then the full load and speed are maintained for an hour. By this duplicate process it is made certain that the engine is fully down to its normal performance before it is installed in the car, and the load of some of the engines is utilized to supply mechanical power for breaking the others to their bearings.

The test-room, which is 120 feet square, contains 100 engine-testing stands arranged in ten rows of ten stands each. Each set includes a 10-h. p., 500/1200 r. p. m., 230-volt, direct-current Westinghouse type S. K. shunt-wound generator, semi-enclosed on the commutator end, and a panelboard carrying control equipment and an ammeter. The great practical advantage of this testing system is not only to save power by the double use of the machines, but particularly in the rapidity and facility in which the tests can be executed. The output of the testing-room is double that with brake equipment, and the quietness of operation resulting from the absence of belts and brakes gives the operators a better opportunity to observe the working of the engine.

Brightness and Contrast. J. KERR. (*The Illuminating Engineer,* vol. x, No. 2, p. 41, February, 1917.)—For a couple of generations or more it has been known that the eye has great power of adjustment in relation to light: a power called *adaptation.* Adapation had scarcely been sufficiently considered in practice and was not clearly defined as the essential factor in differences of lighting till the Society's initial investigations in 1909–1910, dealing with the subject of glare, were conducted. At that time the view was held that the range of adaptation, measured by the sensitiveness of the eye attained in the dark, was twenty or thirty times its sensitiveness in daylight. This estimate has been continually raised by almost every worker in the last half-dozen years, and in the report of a committee of the American Society of Illuminating Engineers it is stated that visual sensibility is fully a million times as great after half an hour's rest in darkness as in broad daylight. Adaptation depends upon the mechanism of the retina and is quite distinct from *accommodation* of the eyes by the lens and the action of the iris.

In any exact vision the eyes are constantly being centred so as to bring the image upon certain sensitive little spots on the retina, the rest of the retina merely giving rough orientaton. In reading, the eyes go along a line in a series of little jumps, fixing a series of such spots in succession, not necessarily in contact, but sufficiently near to give hints of words which the brain can use. For exact work, the more nearly monochromatic the light (with its absence of chromatic aberration), the clearer the image. Too poor an image on the retina may be caused by inadequate light, insufficient contrast, by retinal conditions, or by veiling from the glare of extraneous light, as from a shiny page.

Apparently the maximum brightness for which the eye is prepared through its long course of evolution is the brightest sky, apart from the actual image of the sun. This amount is generally taken at 2.5 to 3 candles to the square inch, and some such amount has been suggested as the standard for any visible sources of light. Indirect lighting may accomplish this. Indirect lighting owes its restfulness to its diffuseness and absence of high intrinsic brilliancy on any surface. The eye is saved much fatigue by absence of violent contrasts and by not having to pass from a comparative dark surface to an incandescent one quite suddenly. On the other hand, it is only through shadows that objects are seen; comparatively shadowless lighting, while useful for general illumination or examination of plane surfaces, reading or writing, is not so useful where small objects or textural surfaces have to be examined. Direct lighting is the most economical method for handling objects or manufacturing processes, but the light source should be kept out of the field of vision or shaded down to the 3-candle-power-per-inch standard.

The matter of contrast which enters into the problem of illumination is of great importance in insuring clear vision; excessive or deficent contrast may be equally troublesome. Experiments in the United States indicated that vision is best with contrasts about 1 : 20, but was possible at 98 : 100. In sunlit scenes out-of-doors, excluding the sun itself, contrasts rarely exceed 1 : 20, indoors not over 1 : 200, although window frames against a bright sky may give a contrast 1 : 10,000. Experience suggests that the ratio be kept below 1 : 100. In full daylight, with the eye adapted to relatively great brightness, even an incandescent filament may not appear very glaring, whereas in the dark a lighted match held near the eye produces a temporary dazzle. In cinema theatres the illumination of the screen will be found to vary from 0.5 foot-candle to 1 foot-candle or more. The ratio 1 : 100 would imply brightness of surroundings of about 0.01 foot-candle, extreme contrast between the brightness of the screen and the general surroundings being objectionable.

The Photometry of Luminous Substances. A. BLOCK. (*The Illuminating Engineer,* vol. x, No. 3, p. 76, March, 1917.)—The measurement of the brightness of fluorescent and phosphorescent substances is rendered difficult by two factors: (1) the color of the light, the spectrum of which usually consists of bands or lines situated mainly in the green or the blue; and (2) the relatively low luminosity. Both these factors tend to introduce the Purkinje effect. Fortunately the chief data required are usually relative, and one can thus work throughout with a colored screen placed in front of the comparison lamp, and designed to give a color which more or less matches the light of the material being tested.

If absolute values of brightness are desired, allowance must be made for the absorption of the screen, but the procedure for effecting this introduces all the physiological difficulties attendant on heterochromatic photometry at low illuminations. An approximate color match can be obtained with relative ease, for example, by the use of signal green glass in testing phosphorescent zinc sulphide. But, unless the spectral composition of the two lights compared is substantially identical, errors may be introduced by the order of luminosity at which the test is made, the part of the retina upon which the image is received, and perhaps, also, by the size of the photometric surface employed. Various photometric methods have been devised for dealing with this class of substances, and in these a color-matching screen is almost always employed.

A point to be borne in mind in speaking of photometrical values of self-luminescent substances is that the luminosity of the material in powder form is considerably higher than when the material is mixed with varnish or other substance to form paint. Moreover, the thickness of the layer tested to some extent determines the foot-candle value. A further factor which may influence the result is the treatment of the substance in regard to exposure to light before the test. In the matter of substances like Balmain's compound this is obviously a matter of prime importance, but with materials depending on radio-active excitants for their luminosity the effect of previous light action is apparently not yet thoroughly known. It is indeed very evident that for the systematic specification of these self-luminous substances standard test conditions still remain to be worked out.

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PHYSICS OF THE AIR*

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INTRODUCTION.

THE physical phenomena of the earth's atmosphere are exceedingly numerous and of great importance. Nevertheless, the explanations, even of those well understood, still remain scattered through many books and numerous journals. Perhaps this is because some of the phenomena have never been explained, and others but imperfectly so, but, however that may be, it is obvious that an orderly assemblage of all those facts and theories that together might be called the *Physics of the Air* would be exceedingly helpful to the student of atmospherics. An attempt to serve this useful purpose led to the production of the following chapters.

The author begs to express his indebtedness to Prof. C. F. Marvin, Chief of the United States Weather Bureau, for numerous helpful criticisms, and to Prof. C. F. Talman, Librarian of the United States Weather Bureau, for valuable aid in locating original sources.

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* These papers on the Physics of the Air, constituting an official report prepared by William J. Humphreys, Professor of Meteorological Physics in the Weather Bureau, are published by The Franklin Institute in coöperation with the Weather Bureau.

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PART I.

Mechanics and Thermodynamics of the Atmosphere.

CHAPTER I.

OBSERVATIONS.

BEFORE discussing any of the physical laws of the atmosphere it will be instructive briefly to consider the observational data upon which they are based; that is, to enumerate the meteorological phenomena which commonly are measured, and to indicate in each case the type of instrument generally used. No effort will be made to describe apparatus in detail, nor to discuss the minutiæ of every correction. These important matters are fully taken care of by observers' instructions issued by the United States Weather Bureau and other meteorological services. Besides, they pertain to the technique of the collection of data rather than to the science deduced therefrom, which latter, and not the former, is the object of the present discussion.

MEASURED PHENOMENA.

Temperature.—Probably the most obvious, satisfactory definition of temperature describes it as *that thermal state of an object which enables it to communicate heat to other objects.* Whenever the heat interchange that always takes place between two objects in thermal communication results in a net loss to the one and gain to the other, the temperature of the former is said to have been higher than that of the latter. If, however, there is no net loss or gain by either, the objects are said to have the same temperature.

Detection of net loss or gain may be accomplished in any one of many ways, some of which are: change of volume; change of state; change of electromotive force, and change of electrical resistance. All these, according to circumstances, afford convenient means of comparing the temperatures of different objects, and of establishing a scale for ready reference. Thus the ordinary mercury thermometer, the alcohol thermometer, adapted to low temperatures, and others of this nature, are based on the fact that, corresponding to equal temperature changes, the volume expansion of the vessel is not the same as that of the contained fluid. Such thermometers, though capable of a high

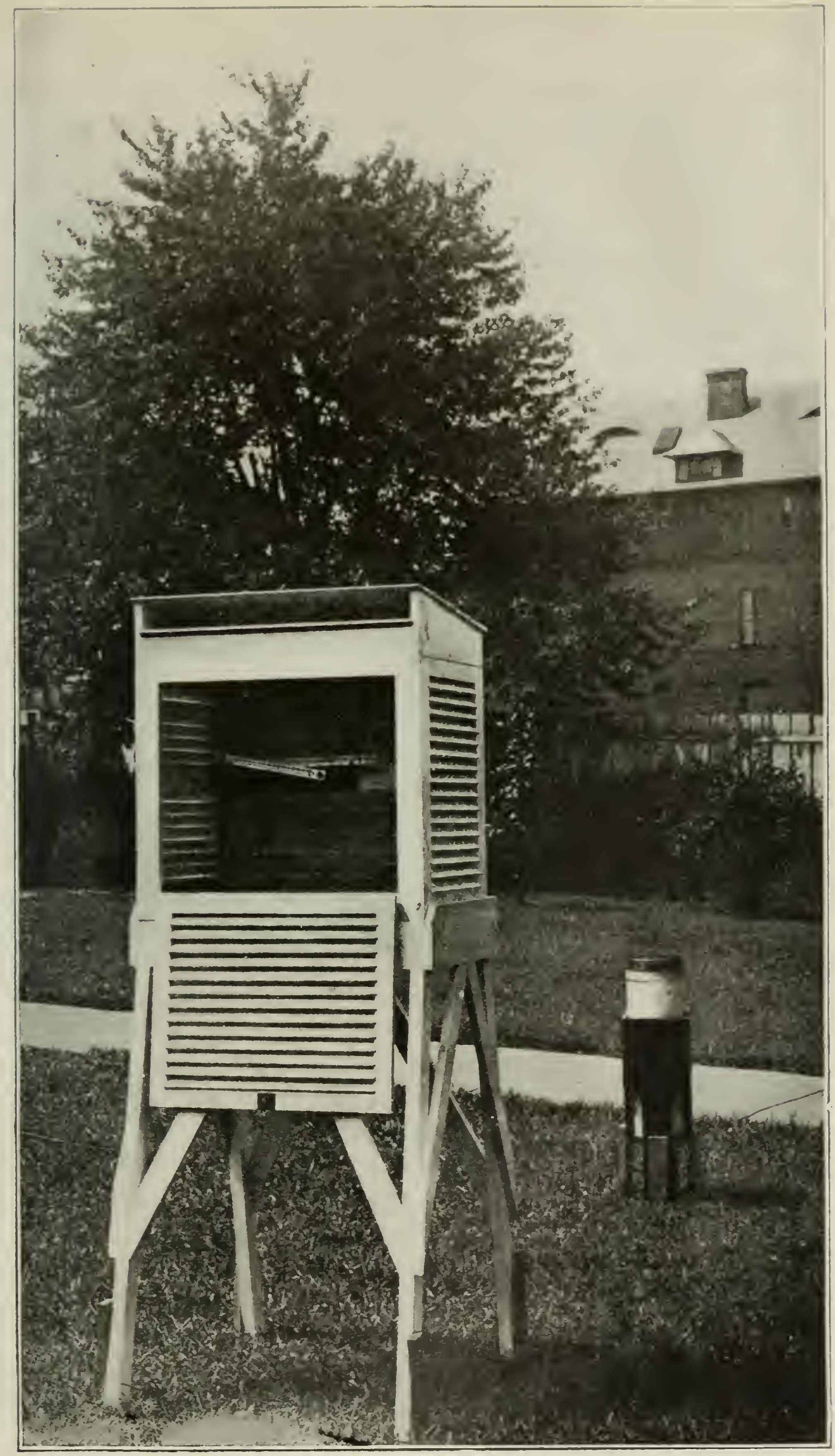


FIG. 1.—Thermometer shelter and rain gauge for coöperative observers.

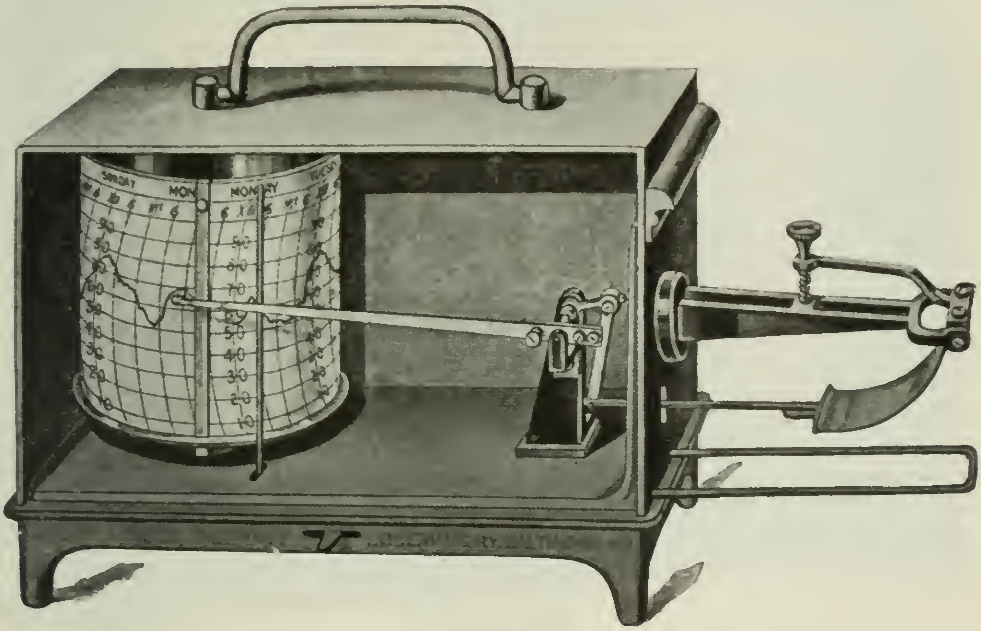
degree of accuracy, are not adapted to cheap and convenient registration, except of extremes; that is, the maximum or minimum temperature reached since last adjustment. Nevertheless, differential expansion does afford several means of obtaining continuous mechanical registration of temperature. The most compact and satisfactory apparatus of this kind in general use consists essentially of a curved closed tube of oval cross-section —a Bourdon tube—completely filled with a suitable liquid. Inequality of expansion between tube and liquid in this case demands change of volume, and that in turn changes the curvature of the tube. Hence by making one end of the tube fast and connecting the other with a tracing point it at once becomes possible to obtain on a moving surface a complete record of temperature changes. The unequal expansion of the two sides of a bimetallic strip is also utilized in obtaining temperature registration.

Variation of electrical resistance with change of temperature and the electromotive force at a thermal junction both provide means of measuring temperature changes to a high degree of accuracy.

In the case of the atmosphere, however, temperature commonly is measured at stated intervals, and whenever desired, by the readings of a good mercurial, or, in very cold regions, alcohol, thermometer exposed to full circulation of the air, but protected from both solar and sky radiation. An excellent shelter for this purpose, with maximum and minimum thermometers in place, is shown in Fig. 1. Normally, of course, the door is closed. A less accurate but continuous record of atmospheric temperature usually is secured by the use of either a bimetallic or a Bourdon tube thermograph (Fig. 2). The connection between the thermal element and the tracing point may be either mechanical, as shown, or electrical. In the latter case the two may be separated any desired distance, the first placed outdoors, say, and the second conveniently located in an office. Other methods of measuring and even continuously recording the temperature of the air have been devised, though at present they are but sparingly used, and then, as a rule, only for special purposes.

Pressure.—The pressure of the atmosphere, upon the distribution of which winds and storm movement so vitally depend, ordinarily, is not determined. Measurements, however, equally good for intercomparison, are made to which it is directly proportional, and from which pressures readily might be computed in dynes per square centimetre, or any other specified units. On land the measurement usually taken for this purpose is the height of the barometric column; that is, the difference in level between the two free surfaces of a continuous mass of mercury, one of which is open to the atmosphere, the other *in vacuo*, slightly corrected for temperature effects, capillarity, scale errors, and degree of vacuum. From this corrected height and the local force of gravity the actual air pressure is easily obtained. Further, by reducing the barometric heights simultaneously obtained at different places to what they presumably would be if the stations all had a certain common level—for which operation appropriate equations are used—data are obtained which, when plotted on a map of the region concerned, show the approximate pressure distribution, from which, in turn, the strength and course of the winds during the next 12 to 24 hours may be closely predicted.

FIG. 2.

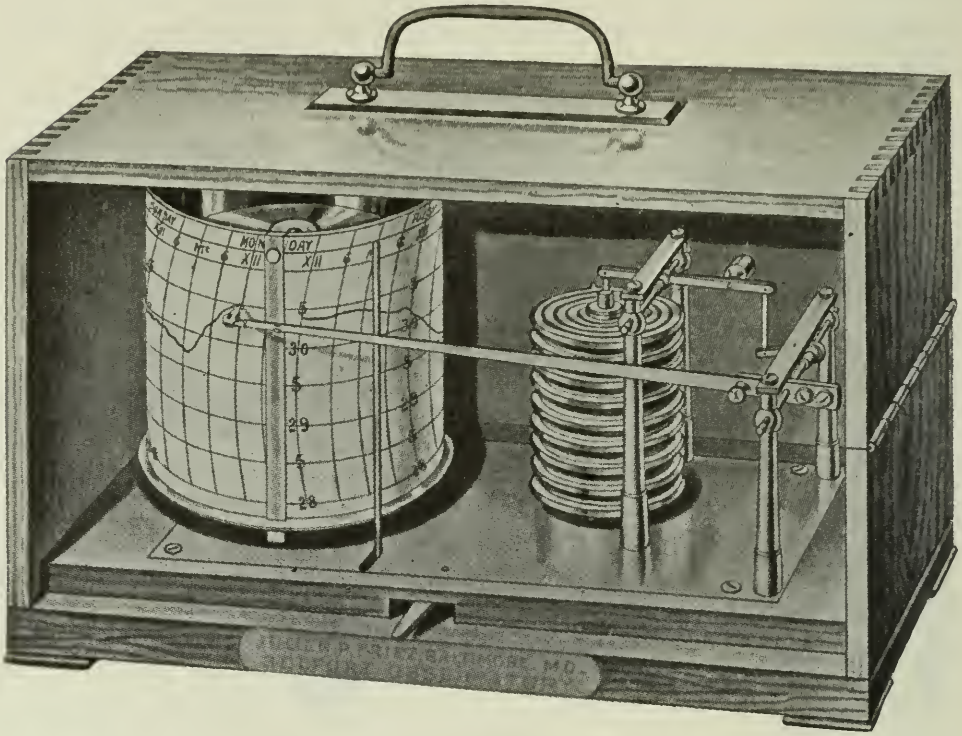


Thermograph.

As a rule, the mercurial barometer is read by eye and only as occasion may require, but it also has been so constructed as to give excellent continuous records.

The aneroid, or, as its name implies, non-liquid, barometer, though involving many sources of error, is conveniently portable and capable of fairly satisfactory use in many places—on kites, aeroplanes, etc.—where the mercurial barometer would be wholly impracticable. It consists essentially of a disk-like vacuum cell, or series of such cells, a few centimetres in diameter, whose corrugated, flexible top and bottom are held apart by a short, stiff spring. Any change in the atmospheric or external pressure obviously must lead to a corresponding flexure of the spring, which motion may be communicated to either an index hand or a recording pen. In the ordinary barograph (Fig. 3) the pen commonly is actuated by a number of aneroid cells placed in series.

FIG. 3.

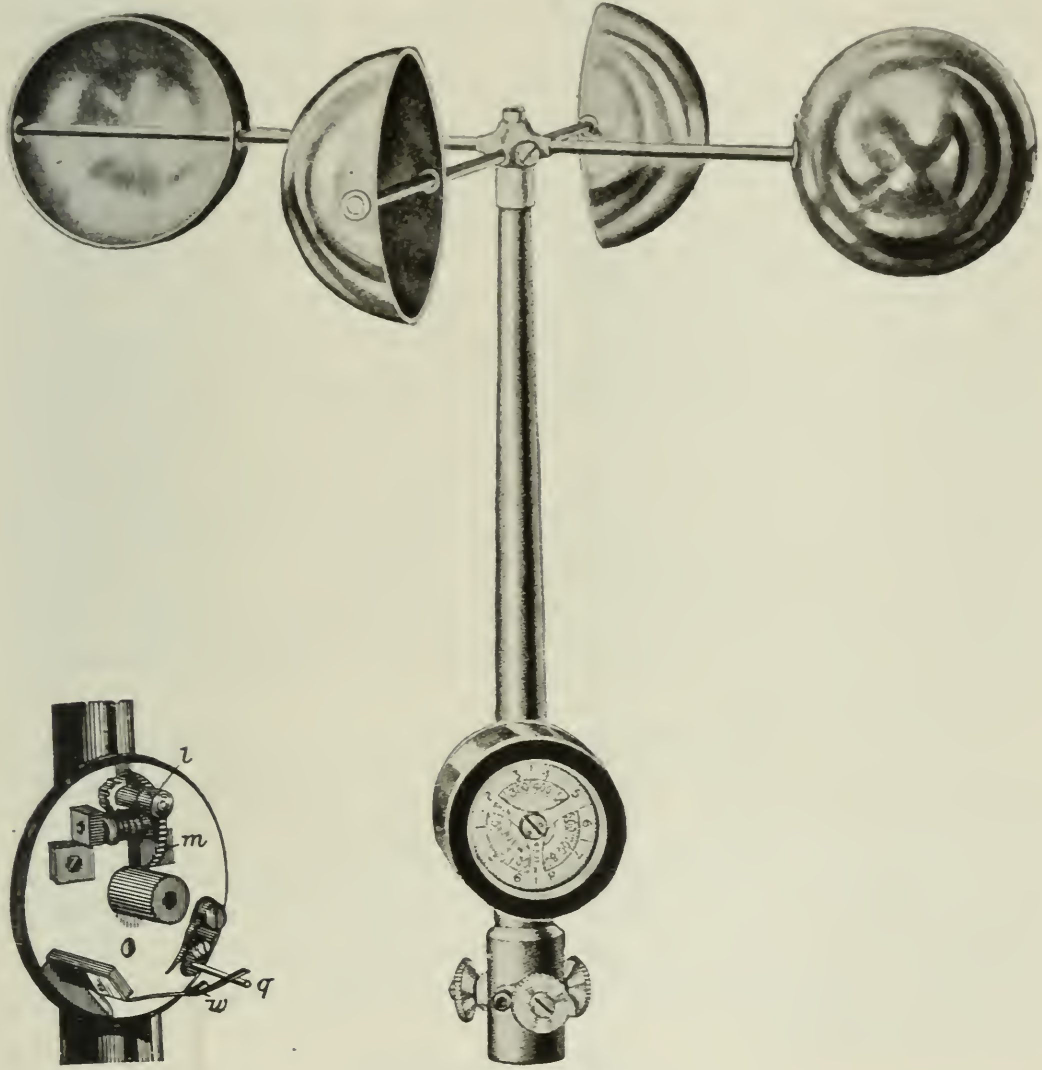


Barograph.

Most aneroids, whether single- or multiple-celled, require careful attention and frequent comparison with a standard mercurial instrument. They also are inherently subject to lag errors due to the imperfect elasticity of the cells that vary according to the pressure conditions and the characteristics of the particular instrument, and which, for accurate readings, must always be allowed for.

Wind Velocity.—The velocity of the wind may be determined by triangulation on clouds, balloons, and other floating objects; by noting the speed of rotation, easily automatically recorded, of a windmill anemometer, air meter, or other similar device, and applying the necessary corrections; by the pressure on a flat surface squarely facing the wind; by the difference in level between the two free surfaces of a liquid in a U-tube or equivalent vessel when one surface is protected and the other exposed to the full force of the wind; and by a great many other but generally less accurate methods.

FIG. 4.



Robinson's cup anemometer.

The Robinson cup anemometer (Fig. 4) appears to be the most convenient and reliable instrument wherever it can be properly exposed. Rapid velocity changes, manifesting themselves in irregular puffs and of great importance to the aviator, the architect, and the engineer, generally are observed and recorded by some quick-acting pressure apparatus, such as the Dines pressure tube anemometer or the Pitot tube.

Wind velocities at considerable heights in the free air commonly are obtained by triangulation on clouds, or—less satisfactorily, owing to constantly changing altitude—on pilot balloons.

Wind Direction.—The direction of the wind, as the term is used in meteorological literature, always means the direction *from* which the wind is blowing at the point in question. It may be determined approximately by the course of smoke, clouds, or other floating objects, by the set of a wind vane (Fig. 5), drift of a pennant, flexure of trees, or other simple methods. Various devices for automatically recording this direction, either in its entirety or for only selected points, are possible, the simplest, perhaps, being electrical and under control of contacts made by a rod connected to and rotated by the wind vane. In common practice only a small number of directions, usually eight, are registered, each covering an angle of 45 degrees. Hence a wind from any point between W. 22.5° S. and W. 22.5° N. is registered as a west wind; and similarly for the other octants. This division may seem very coarse, but it is sufficient for most meteorological uses.

Humidity, Definitions.—The mixture of water vapor with the permanent gases of the atmosphere has occasioned a number of "humidity problems" over which the student is in danger of becoming more or less confused. And this danger is increased by the use in this connection of the same word by recognized authorities to connote quite different ideas. For the sake of clearness, therefore, this subject will be briefly discussed under several sub-heads.

I. *Absolute Humidity.*

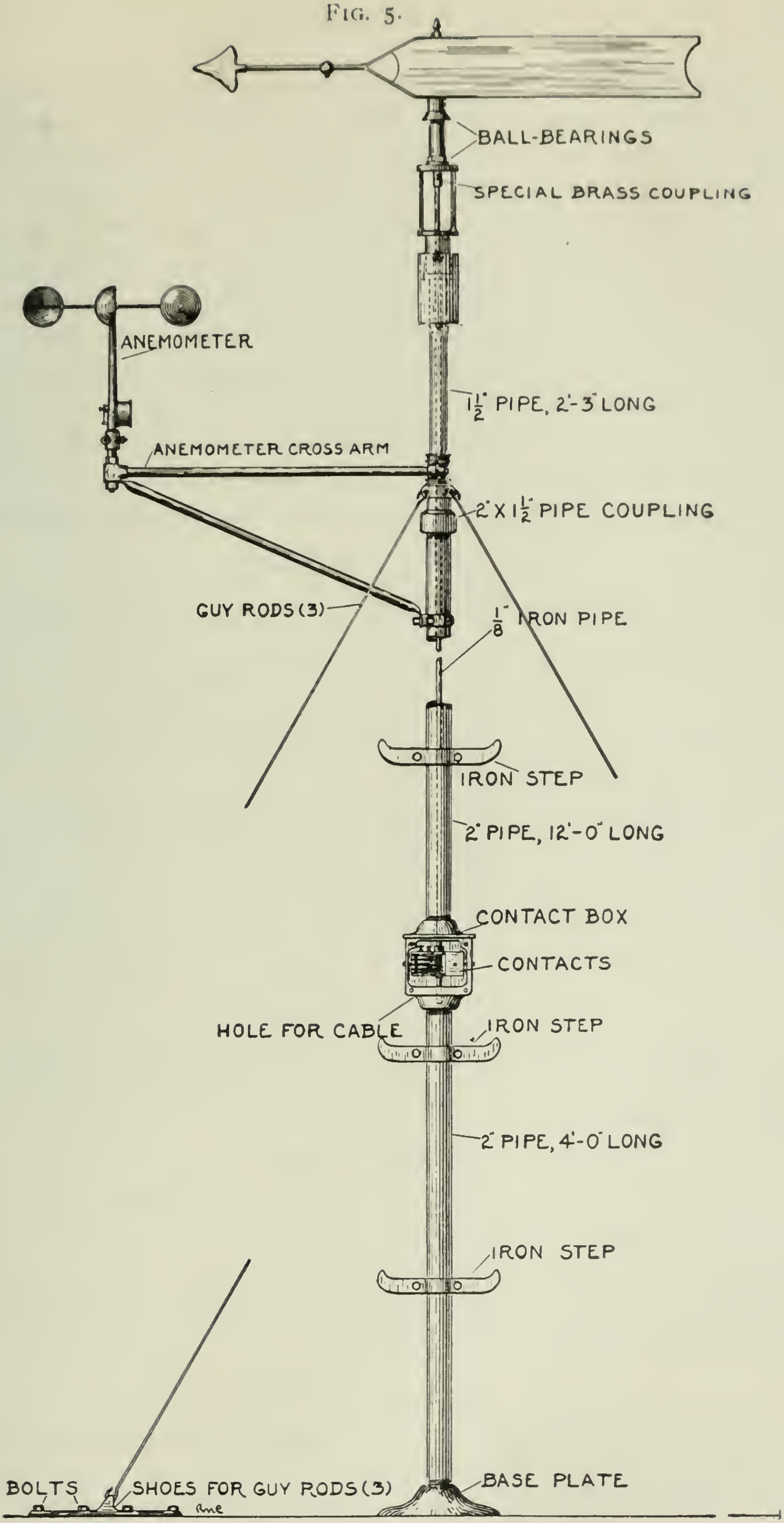
Two entirely different definitions are in use for the common expression "absolute humidity":

a. The mass of water vapor per unit volume.

b. The gas pressure exerted by the water vapor per unit area.

According to the first definition, the absolute humidity may be expressed in terms of any units of mass and volume, as, for instance, grammes per cubic metre.

FIG. 5.



Wind vane and anemometer support, pattern 1913 (showing 4-foot wind vane on ball bearings).

According to the second definition, it may be expressed in terms of any units of force and area—dynes, say, per square centimetre; or any measurable pressure effect, such as height of the mercury column the vapor pressure would sustain.

Accepting the simple definition *a* as being correct, as every one does, it remains to show the equivalence to it of definition *b*. But this follows at once from the well-known fact that the pressure exerted by any constituent in a uniform mixture of gases is to the total pressure as the number of its molecules per given volume is to the total number in the mixture. Vapor pressure, therefore, varies directly as vapor density, or mass per unit volume. Hence the two definitions, *a* and *b*, of absolute humidity are equivalent to each other, for any given temperature.

II. *Relative Humidity.*

Different definitions are also in use for the expression "relative humidity":

a. The ratio of the actual to the saturation quantity of water vapor, at the same temperature, per unit volume.

b. The ratio of the actual to the saturation pressure of water vapor at the same temperature.

In these definitions the expressions "saturation quantity" and "saturation pressure" refer to the maximum quantity of water vapor per unit volume and maximum pressure of water vapor per unit area, respectively, that can exist in the presence of a flat water surface, at the given temperature.

III. *Specific Humidity.*

The term " specific humidity," occasionally found in meteorological literature, means the weight of water vapor per unit weight of moist air.

IV. *Dew Point.*

The expression "dew point," as used in humidity tables and elsewhere, means simply that temperature at which, without change of pressure, saturation is just reached. It might also be defined as that temperature at which the saturation pressure is the same as the existing vapor pressure.

V. *Saturation Deficit.*

" Saturation deficit," a term much used by plant physiologists, is susceptible of several definitions, especially: (1) Amount of water vapor, in addition to that already present, per unit volume, grammes per cubic metre, say, necessary to produce saturation at the existing temperature and pressure. (2) Difference between actual and saturation pressure. (3) Ratio of the vapor pressure deficit to the saturation pressure at the existing temperature. The third is relative, the others absolute.

Humidity, Instrumentation.—The absolute humidity, in the sense of mass of water vapor per unit volume, can be determined by noting the increase in weight of phosphorus pentoxide or other suitable drying agent on absorbing a known volume of the vapor. This direct determination of the humidity, however, is impracticable for routine observations.

On the other hand, as partial pressure ratios are independent of temperature, the determination of the absolute humidity in the sense of vapor pressure merely requires finding the dew point and referring it to a table of predetermined saturation pressures. Similarly, the difference between the current and dew-point temperatures is sufficient to determine, from suitable tables, the relative humidity.

The dew point may be found by any one of several slightly different methods, all of which have for their basis the determination of that temperature at which moisture just begins to collect on a cooling surface. A thin-walled silver tube, burnished on the outside, is an excellent vessel for the cooling mixture. The temperature of the liquid, if well stirred, and that of such a tube will be very nearly the same, and, besides, the dulling of the surface promptly reveals the slightest condensation.

It should be noted, however, that if carefully taken the observed temperatures of the silver hygrometer will be slightly below the actual "dew point." This is because the initial deposit is in the form of minute droplets, whose vapor pressure is greater than that of a flat surface at the same temperature, in accordance with the equation,[1]

$$\triangle p = \frac{2\,T\rho_v}{R\,(\rho_w - \rho_v)}$$

in which Δp is the pressure difference, T the surface tension, R the radius of the droplet, ρ_w and ρ_v the densities of the water and the saturated vapor respectively.

At ordinary temperatures and for droplets whose radii are 10^{-4} cm. (a possible size) the temperature depression, or error,

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[1] Sir William Thomson, *Proc. Roy. Soc.*, ed. 7, p. 63 (1870).

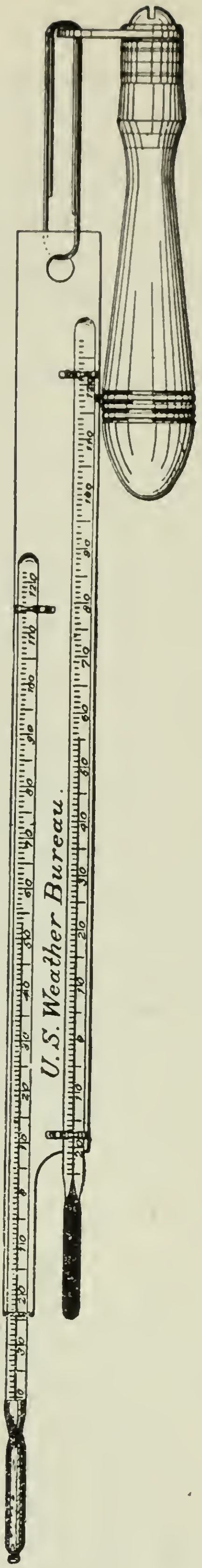


FIG. 6 —Sling psychrometer.

amounts roughly to 0.02° C. According to the equation, the error obviously might have any value, though actually it seems always to be small, owing to limiting values of R, and presumably also to other causes; that is, this too, like many other physical equations, has its limitations.

In taking humidity measurements the observer must be careful that his presence does not affect the amount of moisture in the air under examination—he must stand to the lee of his apparatus. It is also advisable to average the temperature at which dew just forms when the liquid is slowly cooling and that at which it just disappears when the liquid is slowly warming.

A more expeditious and therefore, for routine observations, a correspondingly more practical method of determining vapor pressure is based on the reliability of the equation,

$$f = f_1 - AB\ (t - t_1)$$

in which $t =$ the air temperature.

$t_1 =$ the evaporation temperature; that is, temperature of a vigorously ventilated wet bulb thermometer.

$f =$ the vapor pressure.

$f_1 =$ saturation pressure at temperature t_1.

$B =$ barometric pressure.

$A =$ a number that, in the case of ample ventilation, varies only with t_1, and with it but slowly.

When f, f_1, and B are expressed in millimetres of mercury under standard conditions and t and t_1 in centigrade values,

$$f = f_1 - 0.000660\ B\ (t - t_1)\ (1 + 0.00115\ t_1).$$

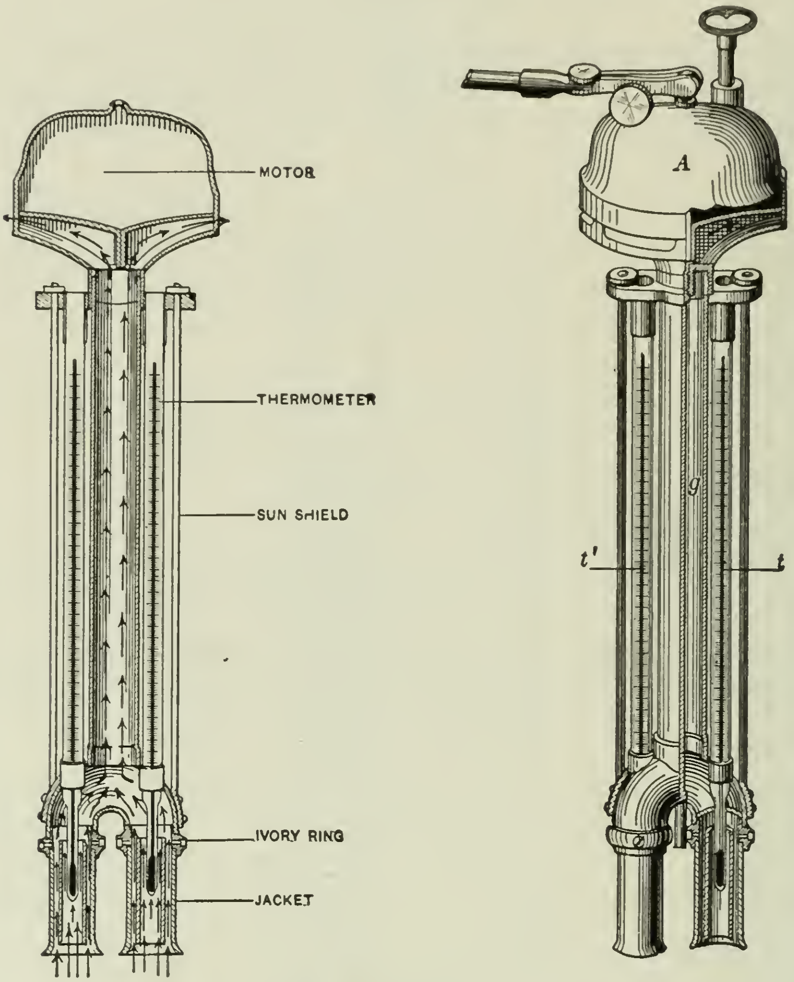
In practice t and t_1 commonly are obtained with a properly constructed and adequately exposed (usually whirled) psychrometer carrying both a wet and a dry bulb thermometer. The sling psychrometer (Fig. 6), whirled by hand, is a simple device for this purpose. The observer has only to note the air temperature, the wet bulb depression (that is, difference between the wet and dry bulb temperatures), and barometric pressure. With these values he reads off from tables the vapor pressure and the dew point.

Assmann's aspiration psychrometer (Fig. 7), however, appears to be the most accurate instrument for this purpose. This consists of two parallel double-walled tubes, silvered to minimize radiation effects, containing a wet and dry bulb thermometer, respectively, united into a common stem and surmounted by a small ventilating fan.

Cloudiness.—The degree of cloudiness generally is expressed in tenths (estimated) of the sky actually overcast.

Kinds of Clouds.—As an indication of the approaching weather and general state of the atmosphere, the kind or kinds of clouds present is more important than the mere total percentage of cloudiness. For convenient reference clouds have been divided into four primary and nine secondary (combination, alto, and fracto) forms.

FIG. 7.



Aspiration psychrometer.

These are:

PRIMARY FORMS: Cirrus—or curl cloud; stratus—or layer cloud; cumulus—or wool-pack cloud; and nimbus —or rain cloud.

COMBINATION FORMS: Cirro-stratus, cirro-cumulus, strato-cumulus, and cumulo-nimbus.

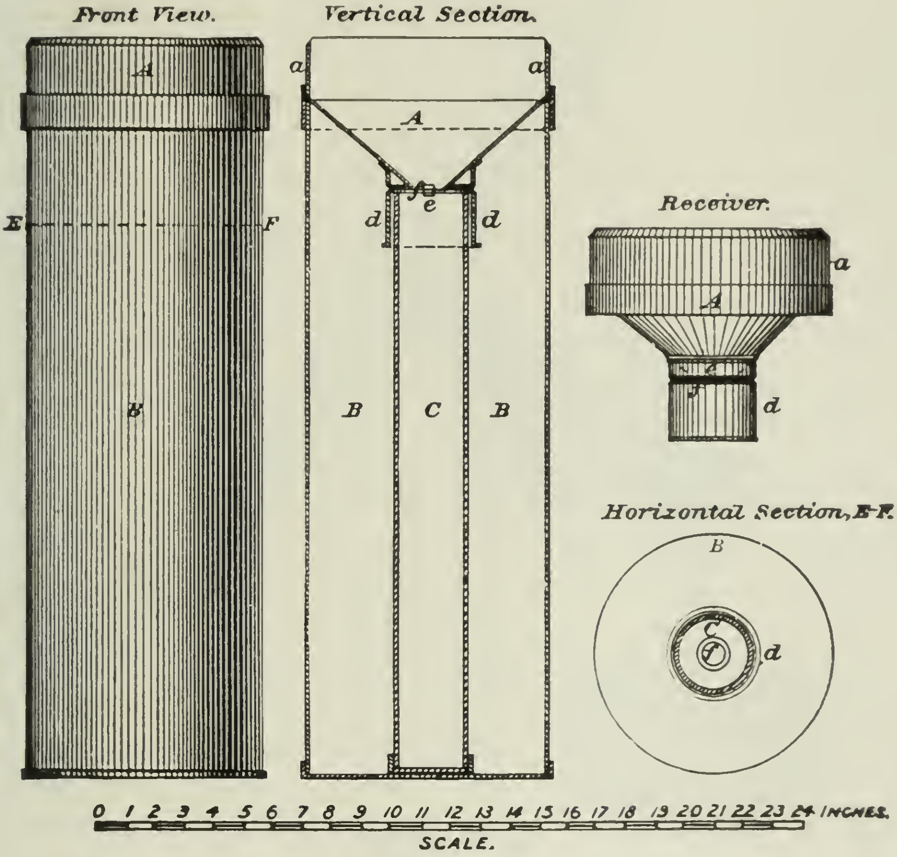
ALTO FORMS: Alto-stratus and alto-cumulus.

FRACTO FORMS: Fracto-stratus, fracto-cumulus, and fracto-nimbus.

The foregoing names are used in the International Cloud Classification, now generally accepted.

It will be noted that several names possible in accordance with this scheme of nomenclature are omitted, even though a few of them have occasionally been used in certain other schemes of classification. Thus there is no cirro-nimbus, for the reason that rain clouds never have the cirrus form; no strato-nimbus, because all rain clouds are flat; no alto-cirrus, because all cirri are high; no alto-nimbus, because rain clouds are never high; and no fracto-cirrus, because cirri are always broken and detached.

FIG. 8.



Rain gauge.

Most of these clouds may be grouped according to their respective altitudes:

UPPER CLOUDS: Cirrus, cirro-stratus.

INTERMEDIATE CLOUDS: Cirro-cumulus, alto-stratus, alto-cumulus.

LOWER CLOUDS: Strato-cumulus, nimbus, fracto-nimbus, stratus, fracto-stratus.

The cumulus, fracto-cumulus, and cumulo-nimbus, all caused by diurnal convection, vary in altitude from low to intermediate.

Precipitation.—The amount of precipitation is measured in the actual or, in case of snow, equivalent depth of horizontal water layer. The details in respect to the manner of catching and measuring precipitation have been greatly varied. The measuring, of course, is simple enough, but it is far from easy to secure a correct catch, owing chiefly to the influence of the vessel itself on the wind currents over and about its mouth and the consequent effect on the amount of precipitation actually caught. The details of a simple rain gauge are shown in Fig. 8, and its installation in Fig. 1. Many gauges are provided with a small tipping bucket just beneath the spout of the receiving funnel, by which the time of occurrence and rate of each rainfall are electrically recorded at any desired place.

Evaporation.—Evaporation is measured in terms of the depth of a flat layer of water, of area equal to that of the evaporating surface. This, too, like precipitation, has been measured by many kinds of apparatus, some of which have been designed with the view of simulating the surface of leaves, or meeting other special conditions. Many attempts have also been made to find from theoretical considerations a correct equation between rate of evaporation and the various factors upon which it depends, such as shape of surface, extent of surface, temperature of the superficial layer, temperature of the air, humidity, barometric pressure, wind velocity, and anything else that might be considered of importance. A few special cases, such as evaporation from flush circular and elliptical water surfaces at constant temperature and in absolutely stagnant atmosphere, appear to have been completely analyzed.[2] But this work, however ingenious, has contributed very little to the solution of the general problem, because in Nature water surfaces are of irregular outline, and all the factors that control evaporation in such a maze of flux and reflux as to render equation testing and evaluation of constants of doubtful accuracy and value. Evaporation, therefore, like most biological and many other phenomena, must be observed and measured; it cannot be computed very accurately as a function of given conditions.

Sunshine.—Sunshine generally is expressed in terms both of hours of its actual and percentage of its possible duration. It is recorded automatically, usually through electrical contact made or broken by the movement of a mercury piston in the stem of a vacuum-enclosed black bulb thermometer (Fig. 9); by charring on prepared cards in the focus of a glass sphere; or by photographic traces on sensitized paper.

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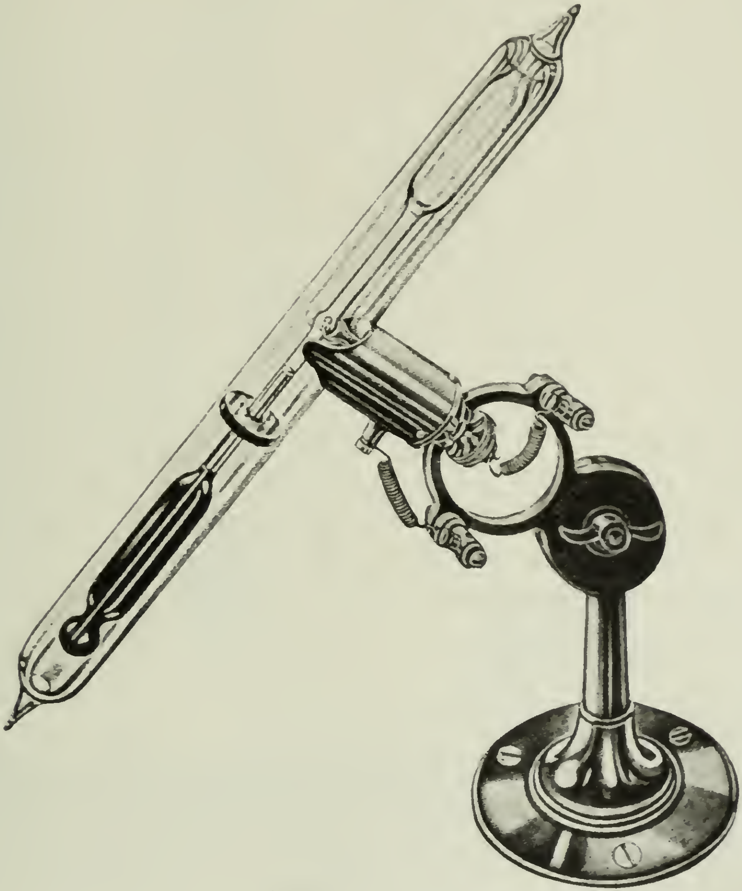
[2] Stefan, *Sitz. der K. Akad.*, 73, 943, 954 (1881).

Radiation.—In relation to the atmosphere, radiation from three sources is of importance: from the sun, from the sky, and from the earth. Each may be measured integrally (that is, in terms of the amount of energy it delivers per minute, say, per unit normal area at the place of observation), or spectrally (that is, as distributed according to wave-length). The first kind of measurement, the integral, usually is made by some type of pyrheliometer, and the second (so far applied only to solar and sky radiation) by a bolometer.

FIG. 9.



Sunshine recorder.

Electrical Condition.—Measurements of the electrical condi-

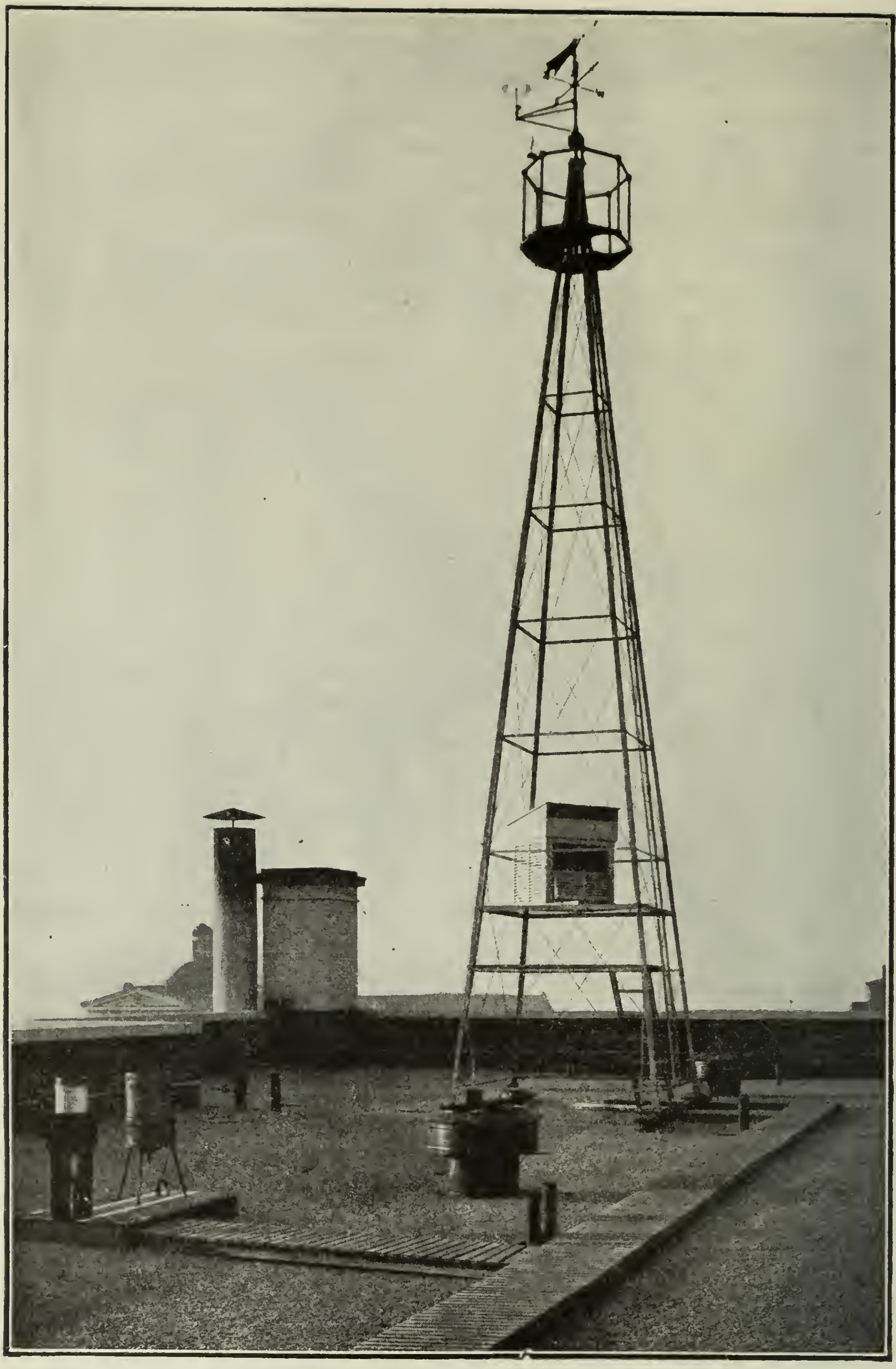


FIG. 10—Forty-foot steel wind instrument tower; typical installation for high office building (Lynchburg, Va., January, 1914.)

tion of the atmosphere generally are confined to the vertical potential gradient, determined by any one of several methods, ionization and the consequent conductivity.

Optical Phenomena.—Various optical phenomena of the atmosphere are observed and recorded. These include, especially, mirages, sky colors, sky polarization, rainbows, coronas, and halos. For several of them—mirages, sky colors, and rainbows—mere eye observations are sufficient. Sky polarization, however, cannot be measured or even detected without the aid of suitable apparatus, while the data pertaining to halos and even coronas are far more valuable when they include accurate angular measurements.

Turbidity.—The turbidity or haze of the atmosphere, whether caused by dust particles (dust haze) or by irregular temperature distribution (optical haze), though often a matter of importance, seldom is measured, and even then only indirectly, since the usual method is to note the maximum distance at which a given object or certain of its details may be distinctly seen. Strictly speaking, this process measures only transparency, from which, however, the inverse, opacity, may be inferred.

Typical Installation.—A typical roof installation of the more common meteorological instruments is shown in Fig. 10. The wind vane is at the top of the tower, the whirling Robinson cup anemometer just below and to the left of the vane, and the sunshine recorder slightly lower, on the cage or platform railing. The thermometer shelter, with the door open, is in the lower portion of the tower. Finally, two rain gauges—one simple, the other tipping bucket—are shown in the lower left corner of the picture.

SOURCES OF METEOROLOGICAL INFORMATION.

As a further introduction to a discussion of the physics of the air, it will be helpful to consider a sort of vertical cross-section of the atmosphere as a whole with reference to the *sources* of meteorological information concerning each particular level. Other cross-sections that show its temperature, pressure, and composition at various elevations will be given later. Fig. 11, an adaptation of Wegener's profile of the atmosphere,[3] indicates the principal present sources of this information and the distribution of meteorological phenomena at various levels.

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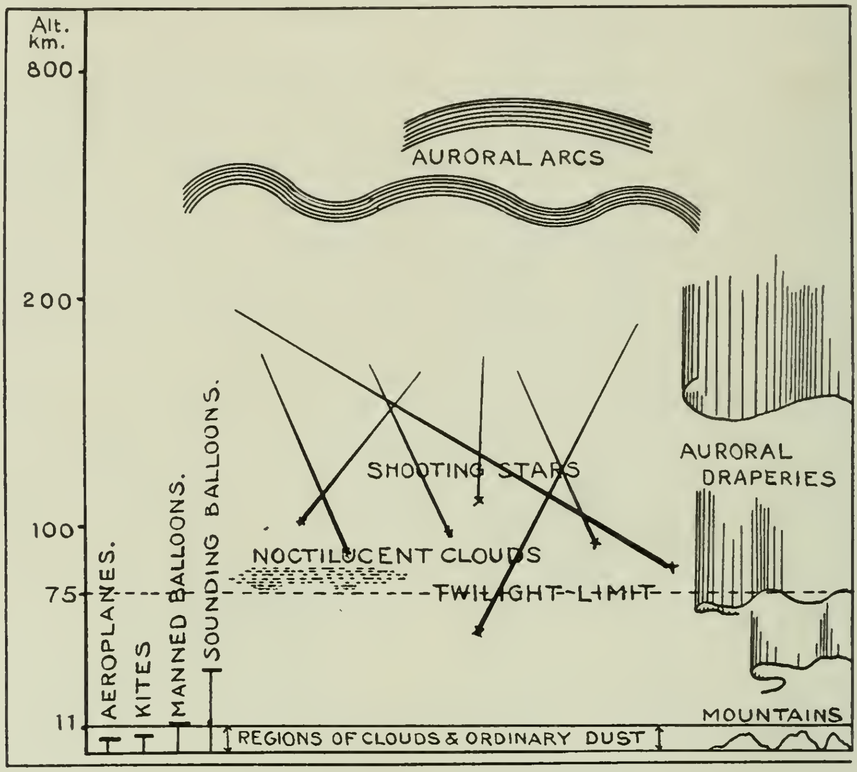
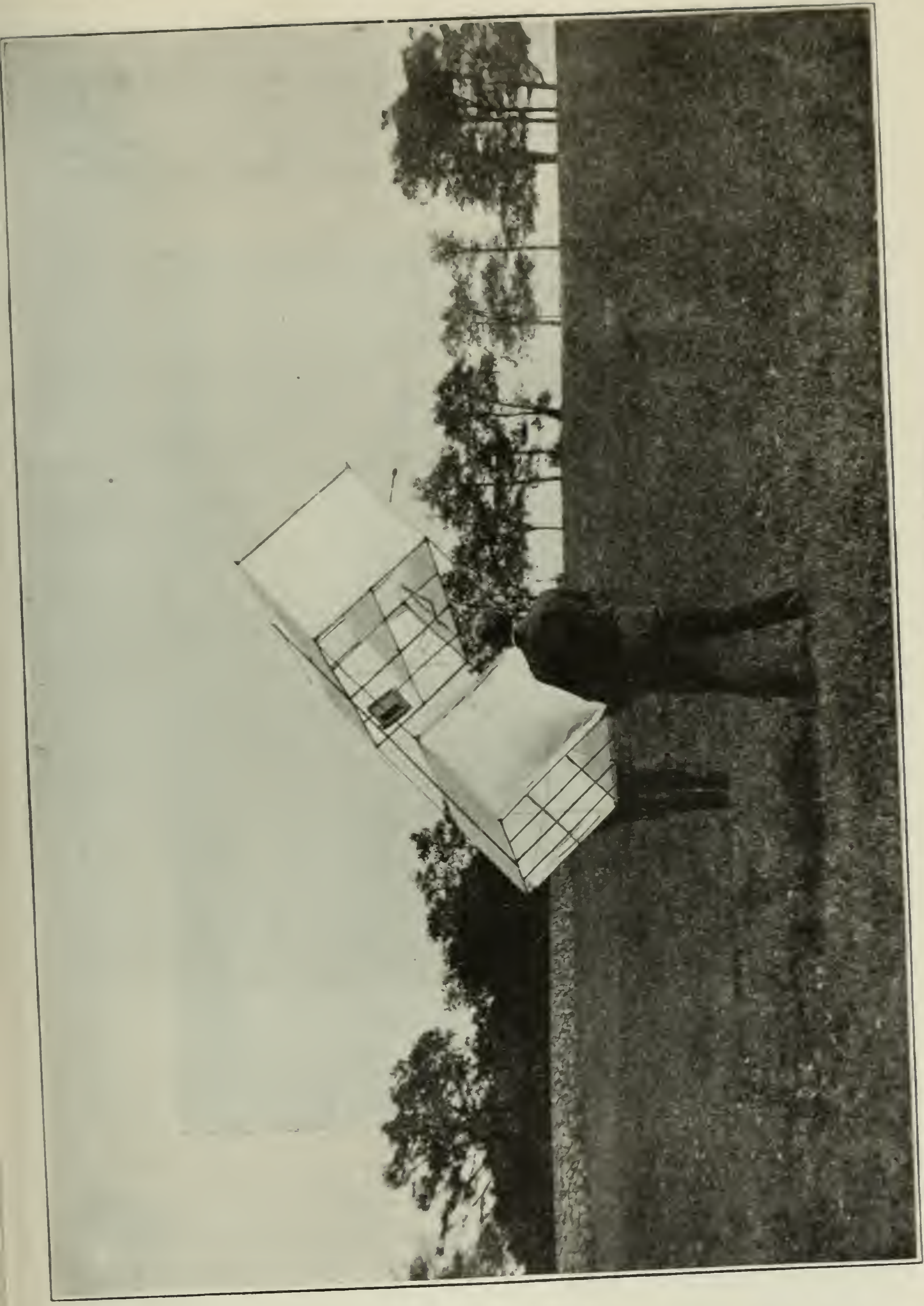
[3] *Phys. Zeitsch.*, 12, Jahrg., 1911, p. 170.

Mountains and other irregularities of the earth's surface make it practicable to examine the atmosphere minutely and to record continuously all its changes at every elevation from sea level up to nearly six kilometres. In fact, many continuous records have already been obtained at the summit station on El Misti, Peru, whose altitude is 5852 metres. Temporary and partial records have been obtained by this means as far up as about 7 kilometres, but no higher, since this is the limit to which any one has ever yet been able to climb. But all such records, whether obtained at high levels or low, of course are more or less affected by the surface conditions. Hence some means of obtaining observations and records other than apparatus carried about on the surface of the earth is essential to a knowledge of the conditions and movements of the free atmosphere. One obvious source of information as regards motion only, and which has been extensively used, consists in the observation of clouds, which occur at all levels from the bottom of the atmosphere up to 11 kilometres, or thereabouts, in middle latitudes, and occasionally, in the tropics, even as high as 15 kilometres.

FIG. 11.



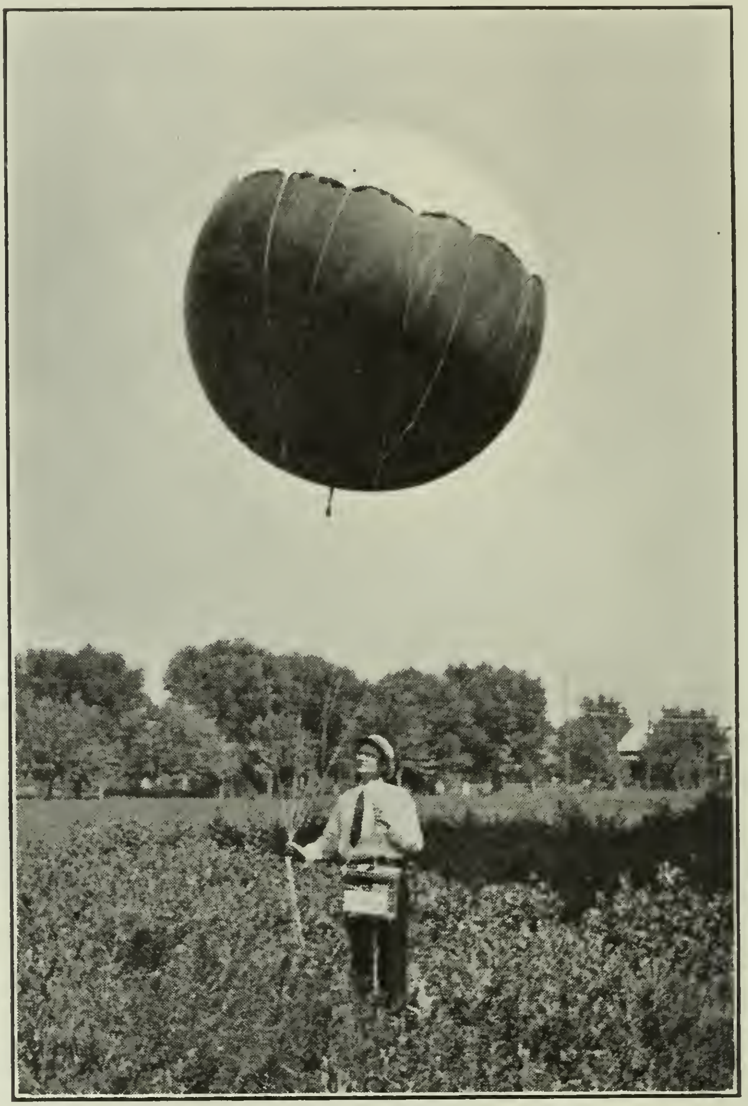
Sources of meteorological information.



Launching meteorological kite, Mount Weather.

There are several methods of determining the elevation, direction of motion, and velocity of clouds, but all depend upon simple processes of triangulation. Thus simultaneous transit observations made on the same spot in a cloud from two stations whose elevations and distance apart are known obviously furnish all the data necessary for an easy and fairly accurate determination of the height of the particular spot in question, while a single subsequent observation by either instrument on this spot, provided the time interval between the first and second observations is known, clearly gives all the additional data neces-

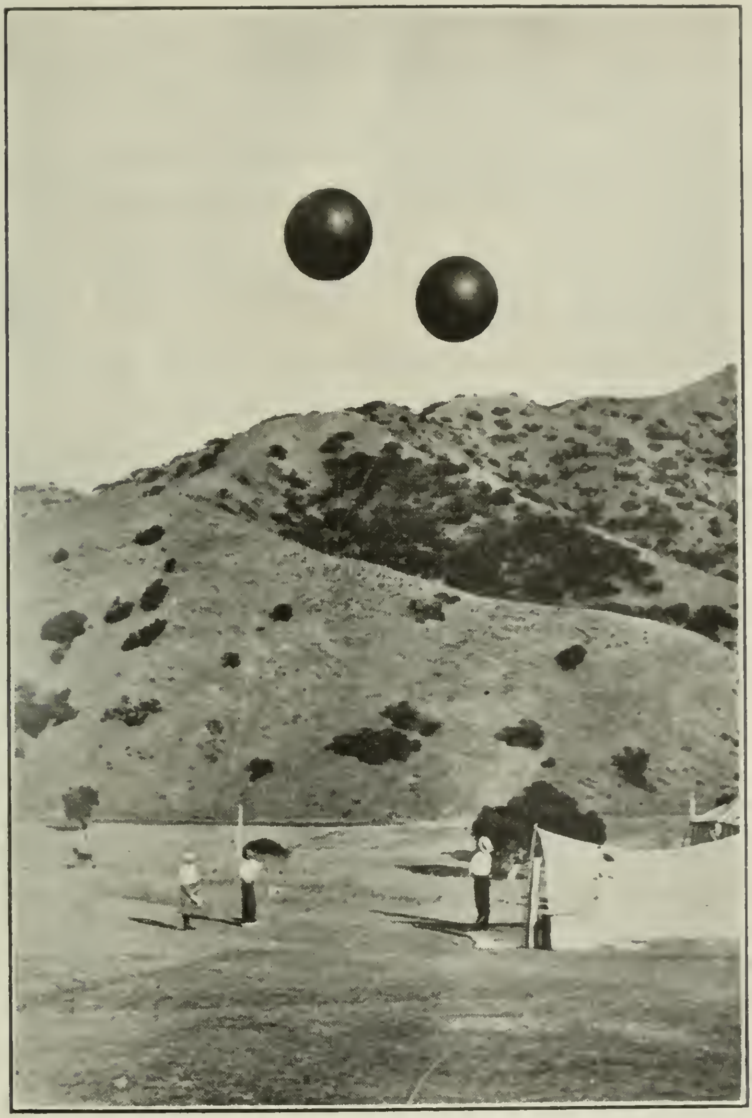
FIG. 13.



Sounding balloon.

sary to the determination of its velocity and direction of motion. Excellent results, also, are gotten from cloud negatives simultaneously obtained with photographic transits provided with fiducial lines. In this way, if several successive exposures are made, the height and movement of each distinguishable point in the cloud can be determined, and therefore not only the general height and drift of the cloud as a whole, but also its dimensions and something of its internal motions. However, the general motion of the wind at the point observed and time of observation, though interesting and often valuable, practically is all the information about the atmosphere that clouds give, and,

FIG. 14.



Sounding balloon.

indeed, some, such as those formed by air billows over mountain crests and elsewhere, do not give even this. Besides, they are not always present, so that on clear days even this modicum of information about the upper air would be impossible to obtain if we had no other means of investigation. But there are others, the most fruitful of which is the carrying of self-registering thermometers, barometers, hygrometers, and the like into the free air by means of:

a. Kites (Fig. 12) to over 7 kilometres, the record being 7.26 kilometres.
b. Aeroplanes; present limit about 8 kilometres.
c. Manned balloons; maximum elevation, roughly, 11 kilometres.
d. Sounding balloons (Figs. 13 and 14), with a record of 35.08 kilometres.
e. Pilot balloons, small balloons without apparatus; maximum elevation reported, 39 kilometres.

The registering apparatus sent aloft by these various methods furnishes reliable information concerning the composition (including humidity), temperature, pressure, direction of motion, and, in some cases, velocity of the air, from the surface of the earth up to the greatest elevation reached. And it is this automatically recorded information, gathered, with but little exception, since the beginning of the twentieth century, that has so greatly extended our accurate knowledge of meteorology, and done so much to make of it an interesting and profitable branch of both theoretical and applied physics.

Beyond the reach of the pilot balloon, or, for the present, at elevations greater than 39 kilometres, our information of the atmosphere is limited to such deductions as properly may be drawn from the height of the twilight arch—roughly, 75 kilometres; the paths of shooting stars, rarely, if ever, seen as high as 200 kilometres; and the phenomena of the auroras, those curious and but partially explained electrical discharges that seldom occur at a lower level than 90 kilometres or higher than 300.

The above obviously are all, or nearly all, the means by which our knowledge of the atmosphere has been obtained. Up to 35 kilometres it is comparatively well known, but beyond that level only deductions, growing less certain with increase of elevation, can possibly take us at present, or at any time until higher soundings have been made.

CHAPTER II.

SOME THEORETICAL TEMPERATURE RELATIONS OF THE ATMOSPHERE.

WITH the object of more clearly understanding the causes of the actual distribution of temperature in the atmosphere, it will be convenient, first, to consider some of the thermodynamic equations of gases, especially those that give relations between temperature, pressure, and volume.

If to a unit mass of air or other gas at constant pressure p a quantity of heat dQ be supplied, the energy so added will divide itself into two parts. One portion will change the temperature of the gas and the other will change its volume. Hence, if the work is expressed in its heat equivalent, or if each portion of the energy is expressed in heat units and not in units of work, then

$$d\,Q = C_v\,d\,T + A\,p\,dV \qquad (1)$$

in which C_v is the specific heat of the gas in question at constant volume, dT and dV the resulting changes in temperature and volume, respectively, and A the reciprocal of the mechanical equivalent of a unit of heat.

But to secure the relations desired, the relation of p to T, for instance, when both are variable, it is necessary to have an additional equation involving dT, dp, and dV. From Boyle's and Charles's laws, we have the equation,

$$pV = \frac{p_o\,V_o}{T_o}\,T,$$

which expresses the fact that for a given quantity of gas the product of pressure and volume varies directly as the absolute temperature, T. So long, then, as the quantity of gas involved and its temperature are constant, so also is the product pV. But when this quantity is one gramme and the temperature 0° C., it is convenient to speak of the quantity, $\frac{p_o\,V_o}{T_o}$, as the characteristic constant, R, of the gas in question. In general, then,

$$pV = RT,$$

in which the value of R depends solely upon the kind of gas.

Hence, differentiating,

$$p\,dV + V\,dp = R\,dT. \qquad (2)$$

To find the relation between dp and dT in an adiabatic process (that is, a process in the course of which no heat is either given to or taken from the gas involved, such as closely obtains in the case of rapidly rising or falling air), it is only necessary, by aid of equation (2), to eliminate dV from equation (1) and to put $dQ = 0$.

Thus

$$C_v\, dT + A(R\, dT - V\, dp) = 0$$

or

$$(C_v + AR)\, dT = AV\, dp. \quad \dots\dots\dots\dots (3)$$

Also, since the excess of the specific heat at constant pressure over the specific heat at constant volume is simply the amount of heat necessary to perform the external work incident to expansion as a result of increasing the temperature 1° C., we have,

$$C_p - C_v = AW, \text{ the heat equivalent of the external work.}$$

And from $pV = RT$, we get, with p constant,

$$p\, dV = R\, dT.$$

If $dT = 1°$ C., then $Ap\, dV$ is the heat equivalent of the external work done as a result of increasing the temperature of the unit mass of the gas in question 1° C. Hence,

$$C_p - C_v = AR.$$

On substituting this value of R in (3), we get,

$$C_p\, dT = A\, V dp,$$

or

$$\frac{dT}{dp} = \frac{AV}{C_p} = \frac{ART}{pC_p} \quad \dots\dots\dots\dots (4)$$

From this it appears that the ratio of the change of temperature to the change of pressure, in an adiabatic process, is directly proportional to the absolute temperature and inversely proportional to the pressure.

In the case of dry atmospheric air at ordinary temperatures $C_p = 0.241$, about.[4] Hence,

$$dT = dp \frac{ART}{p\ 0.241}.$$

But

$$R = \frac{p_o V_o}{T_o} = \frac{p_o}{\rho_o T_o},$$

from which, assuming p_o to be the pressure in dynes per square centimetre when the barometer under normal gravity and at 0°

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[4] Moody, *Phys. Rev.*, 34, p. 275 (1912).

C. stands at 760 mm., and that ρ_0 is the corresponding density of air at 0° C., it follows that, numerically,

$$R = \frac{1033.3 \times 981}{0.001293 \times 273} = 2.871 \times 10^6;$$

and

$$A = \frac{1}{4.19 \times 10^7}.$$

Therefore,

$$dT = \frac{dp}{p} \frac{T}{3.5172},$$

and

$$\frac{dT}{T} = .2843 \frac{dp}{p}.$$

In the special case where the pressure is one atmosphere (barometer reading 760 mm.) and the temperature 0° C. (273° absolute), such as often happens on the surface of the earth, an adiabatic change of pressure represented by 1 mm. of the barometer produces a temperature change given by the equation,

$$dT = \frac{1}{760} \frac{273}{3.5172} = 0^\circ.10213 \text{ C.}$$

From equation (4) we get

$$\frac{dT}{T} = \frac{dp}{p} \frac{AR}{C_p}$$

Hence

$$\log_e \frac{T_1}{T_2} = \frac{AR}{C_p} \log_e \frac{p_1}{p_2}$$

or,

$$\frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{AR}{C_p}} = \left(\frac{p_1}{p_2}\right)^{\frac{C_p - C_v}{C_p}} = \left(\frac{p_1}{p_2}\right)^{0.286},$$

or,

$$\frac{p_1}{p_2} = \left(\frac{T_1}{T_2}\right)^{3.50}.$$

If we wish to find the rate of adiabatic cooling with change of elevation, *dh*, a matter of great meteorological importance, it is necessary to find the value of *dp* in terms of *dh* and substitute in equation (4). It must be remembered, too, that the pressure *p* decreases as the height *h* increases.

But $-dp = 981\,\rho\,dh$, where ρ is the density of the gas in question, or

$$-dp = \frac{981\,dh}{V} = \frac{981\,p\,dh}{RT}.$$

Hence, by substitution in equation (4), as explained,

$$-\frac{dT}{dh} = \frac{981\,A}{C_p} = \frac{1}{10293} \quad \text{..........................(5)}$$

Clearly, then, when the atmosphere is dry and its temperature decreases with increase of altitude at the above adiabatic rate of 1° C. per 102.93 metres, any portion of it transferred without gain or loss of heat from one level to another has, at every stage, the same temperature and density as the adjacent air, and therefore, if abandoned at rest, will neither rise nor fall. If, however, the temperature decreases with altitude at a less rate than the above, an isolated mass of air, on being adiabatically lifted or depressed, becomes colder and denser or warmer and rarer, respectively, than the adjacent air, and consequently, if abandoned, will return to its initial level. Finally, if the temperature decrease with altitude is more rapid than the above rate, an isolated mass of air, on being elevated or depressed, will become warmer and lighter or colder and denser than the adjacent air, and, if permitted, will continue to rise or fall, respectively, until arrested by a change in the temperature gradient, or, if descending, perhaps even by the surface of the earth.

In short, the atmosphere is in neutral, stable, or unstable equilibrium according as the temperature decrease with increase of altitude is the same as, less than, or greater than the adiabatic rate of 1° C. per 102.93 metres.

From equation (5) it is obvious that the adiabatic rate of temperature decrease of the atmosphere with increase of altitude is independent alike of altitude, temperature, and pressure, unless, possibly, its specific heat at constant pressure may slightly vary with temperature or pressure, or both. When, however, the composition of the atmosphere is changed, it is obvious that its specific heat, and therefore its temperature gradient, must also change. Now the chief variable constituent of the atmosphere is water vapor, and, since its specific heat is approximately 1.6 that of dry air, it follows that the greater the amount of water vapor present the less rapid will be the adiabatic decrease of temperature with increase of altitude.

Water vapor also frequently causes another and most important change in the temperature gradient. As soon as condensation sets in the latent heat of vaporization, and, if ice is formed, of fusion, is liberated, and thus the rate of temperature decrease with altitude is reduced. The amount of this reduction, often at least half the original value, depends, of course, slightly upon what becomes of the condensed vapor. If it is carried along with the rising air the process remains adiabatic, except as slightly modified by conduction and radiation, but if, as in great measure must happen, it is left behind as precipitation, then the process becomes that special case of the nonadiabatic which von Bezold, followed by others, has called pseudoadiabatic. This whole subject has been more or less discussed by several writers, but most fully, first, by Hertz[5] and, later, by Neuhoff.[6]

Undoubtedly much of the condensation drops out, or begins to drop out, as soon as formed, so that the actual temperature gradient, while lying somewhere between the really adiabatic and the "pseudoadiabatic" curves, probably follows the latter more closely than the former. Presumably, therefore, in practice it would be better, or at least quite as well, to determine the latter gradient (the adiabatic will be considered later, under "Condensation," in the chapter on "Humidity") and then to add such corrections to it as the circumstances of individual cases suggest. The main curve can be determined as follows:

As before,

$$dQ = C_v\, dT + Ap\, dv.$$

But

$pV = RT$, (R being appropriate to the existing mixture of air and water vapor).

Hence

$$\begin{aligned} dQ &= C_v dT + A(R\, dT - V\, dp) \\ &= (C_v + AR) dT - A\, V\, dp \\ &= C_p dT - A\, V\, dp \end{aligned}$$

But

$$-dp = g\rho dh,$$

where g is gravitational acceleration.

Therefore,

$$dQ = C_p dT + g\, A\, dh.$$

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[5] *Deutsch. Met. Zeit.*, vol. i, 1884, p. 421.

[6] *Abh. d. K. P. Met. Inst.*, vol. i, No. 6, Berlin, 1900.

Now the heat, dQ, is added as the result of a quantity of water vapor, dw, being extracted. Hence

$$dQ = -s\,dw,$$

in which s is the heat of vaporization, and therefore,

$$-s\,dw = C_p dT + g\,A\,dh.$$

From this equation it is obvious that to obtain the ratio of dT to dh in terms of measurable quantities it is necessary and sufficient to express dw in similar terms.

But

$$w = \rho\, 0.622\, \frac{e}{b},$$

in which w is the total mass of water vapor per cm.,^{3} ρ the density of the air, 0.622 the ratio of the molecular weight of water vapor to the weighted mean of the molecular weights of the constituents of dry air, e the partial pressure of the water vapor in terms of millimetres, say, of mercury, and b the height, in millimetres, of the barometer.

Hence

$$\frac{dw}{w} = \frac{de}{e} - \frac{db}{b}.$$

But, if D is the density of mercury,

$$-D\,db = \rho\,dh = \frac{p\,dh}{RT} = \frac{D\,b\,g\,dh}{RT}.$$

Hence

$$-\frac{db}{b} = g\,\frac{dh}{RT}.$$

and

$$dw = w\frac{de}{e} + wg\,\frac{dh}{RT}.$$

Hence, by substitution,

$$C_p\,dT + sw\frac{de}{e} + swg\,\frac{dh}{RT} + gA\,dh = 0$$

or

$$\left(C_p + sw\frac{de}{e\,dT}\right)dT + \left(\frac{sw}{RT} + A\right)g\,dh = 0$$

and

$$\frac{dT}{dh} = -\frac{g\left(A + \frac{sw}{RT}\right)}{C_p + sw\,\frac{de}{e\,dT}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

All the terms on the right-hand side of this equation are known for any definite temperature and assumed value of dT. From this equation, therefore, tables can be written and curves constructed that give the "pseudoadiabatic" gradient under all conditions of temperature and pressure.

CHAPTER III.

OBSERVED VERTICAL TEMPERATURE GRADIENTS.

THE temperature of the surface air is well known at many places and at various altitudes, from sea level up to about six kilometres. But the temperature records obtained by the aid of kites and balloons, both manned and free, show that the mountain air temperatures generally differ materially from the temperature of the free air at the same elevation and latitude.

According to Hann,[7] the average temperature of the surface decreases approximately at the rate of 1° per each 180 metres, 200 metres, and 250 metres increase of elevation on mountains, hills, and plateaus respectively. In the free atmosphere, however, the result is quite different. Here the decrease of temperature with increase of altitude, except at very great elevations, is, roughly, the same at different parts of the world.

The records obtained by kites, manned balloons, and sounding balloons, of course, all agree, so far as they apply to the same levels, but as the free or sounding balloon, with its automatically registering apparatus, has gone far higher than either manned balloons or kites, and as ascensions by it have been quite numerous, only the records thus obtained will be considered in what follows. Again, and for the sake of still further uniformity, the first part of the discussion will be confined to only those records which were obtained at Munich, Strassburg, Trappes, and Uccle, four European stations of about the same latitude and more or less similar climates. It seems also desirable to divide the records of vertical temperature distribution according to season, winter (December, January, February, and March) and summer (June, July, August, and September), and prevailing type of weather, or, to be more exact, the height of the barometer, high, low, and neutral. Spring and fall observations will not be used in the typical or most general temperature distributions, owing to the transitional nature of these seasons, or the overlapping and confusion at these times of summer and winter conditions.

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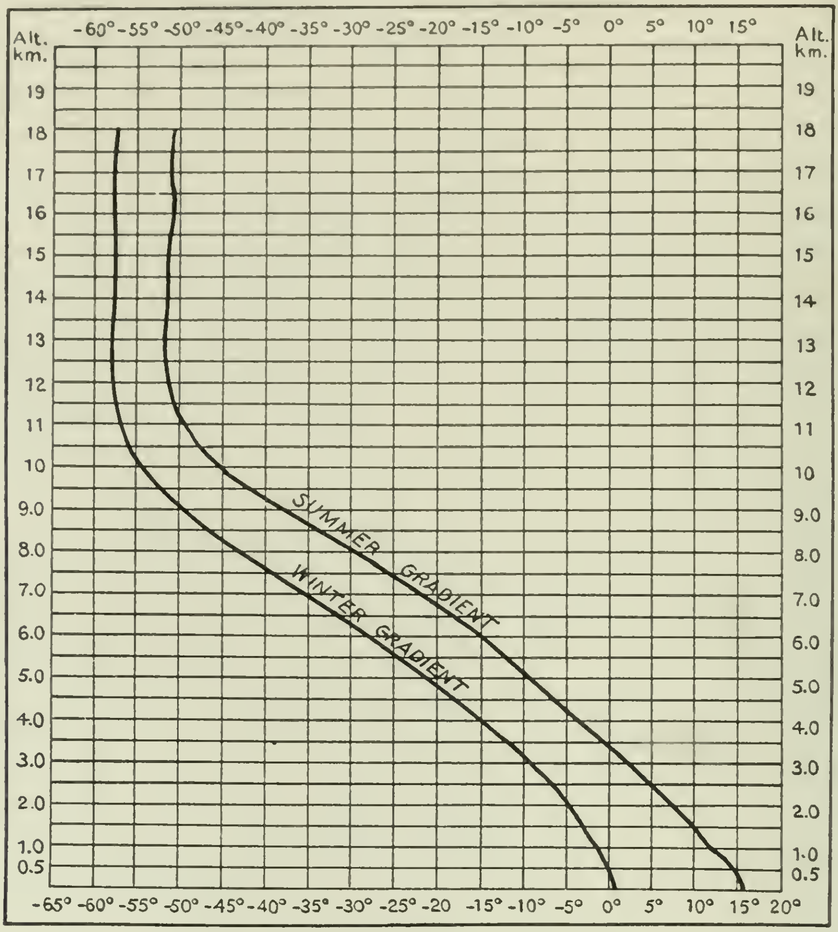
[7] "Lehrbuch der Meteorologie," 3d ed., p. 126.

At the time these data were assembled, the early part of 1910, all the published records of the stations mentioned were used, there being 52 winter records and 65 summer records. A larger number of flights would, of course, furnish a somewhat more reliable average, but, as the several stations gave substantially the same results, it would seem that no great change would be made in the season averages, however large the number of combined observations.

FIG. 15.



Winter and summer vertical temperature gradients.

Fig. 15 gives the average winter and summer vertical temperature gradients of the stations in question, or the graphs obtained by plotting the average of the observed temperatures of the given season against the corresponding altitudes at which they were obtained.

A number of interesting points are brought out by these two curves, each of which calls for an explanation. Among other things, the two gradients are, roughly, parallel to each other throughout their whole range. This is because the temperature of the atmosphere from top to bottom is determined by the same factors in the winter that determine it in the summer; that is, by radiation, conduction, and convection, all mainly from the surface of the earth and the lower atmosphere. Since all these factors are less in winter than in summer, it follows that their combined result, the temperature of the higher atmosphere, must also be less at every level; hence the substantial parallelism of the two gradients.

Again, it appears, as shown by the figure, that up to about 2½ kilometres the temperature decreases less rapidly with increase of elevation during winter than it does during summer. The reason for this, while not quite obvious, will become apparent from the following considerations:

The surface of the earth, which is a much better radiator than the atmosphere, often cools, especially during clear nights, to a decidedly lower temperature than the air 100 metres or so above it. Hence late at night, when the sky is clear and there is no wind, the temperature near the surface usually increases with increase of elevation, and even when there is sufficient wind to prevent this "temperature inversion," as it is called, the lower atmosphere still is colder than it otherwise would be. Obviously, too, the amount of this surface cooling, and therefore the magnitude of the temperature inversion, depends jointly upon the rates of radiation to and from the sky and the time involved. Now the rate of the output of surface and lower air radiation is less in winter than in summer, both because of their lower temperatures at that time and because the atmosphere then contains less water vapor, its chief radiating constituent. Hence, although, owing to higher temperatures, both the radiation loss from the surface of the earth and adjacent air and their radiation gain from the upper air are greater in summer than in winter, the difference, or net loss, may usually be less.

At any rate, partly for this reason, it may be, but mainly because of the relatively greater length of the nights and greater dryness and consequent diathermacy of the atmosphere, the total surface cooling, and therefore the morning temperature inversions, is much more pronounced in winter than in summer. Hence the average decrease of temperature with increase of elevation through the first one or two kilometres is decidedly less during the colder than during the warmer season.

Another peculiarity shown by the curves is the fact that between the elevations of approximately four and eight kilometres the temperature decreases rather more rapidly during winter than summer. Throughout this region the temperature of the atmosphere depends in part upon convection from lower levels and in part upon its gain and loss of heat through radiation. But even this midair, or radiational, change in temperature can result only in immediate convection. Consequently, so long as saturation is not reached, the convectional temperature gradient must be very approximately that of a totally dry atmosphere. If, however, condensation takes place, the latent heat of vaporization becomes sensible heat, and the decrease of temperature with increase of altitude is correspondingly less. When a condensation temperature gradient is once established in this mid-region of the atmosphere it tends to persist, even after condensation has ceased and the clouds have evaporated, because, whatever condition—the presence or absence of sunshine, for instance—produces a temperature change in one part of it is likely to produce similar temperature changes in other parts, and therefore a dry air adiabatic variation for each level, a variation which would leave the general temperature gradient substantially as before. We should, then, expect to find the average vertical temperature gradient following, roughly, the gradient for saturated air for the given temperature, and such, indeed, are the gradients actually found.

Hence, as the atmosphere between the elevations of four and eight kilometres is quite out of the reach of surface inversions, and as it is also warmer and more humid during summer than during winter, we should expect the summer temperature of this region to decrease less rapidly with increase of altitude than does the winter temperature, precisely as balloon records show to be the case.

Another point brought out by Fig. 15 is the fact that up to eight kilometres, or thereabouts, the ratio of the decrease of temperature to increase of altitude itself increases with altitude. The explanation of this phenomenon is precisely the same as that of the difference between the winter and summer gradients from four to eight kilometres. That is to say, it depends upon the amount of water vapor necessary to produce saturation at the various levels, since the less this vapor is in proportion to the total gases present the more nearly does the actual temperature gradient follow the adiabatic curve for dry air.

One striking feature of each of the temperature gradients is its gradual change, between the levels of nine and twelve kilometres, from a rapid decrease of temperature with increase of elevation to an approximately isothermal condition. Normally, however, the temperature gradient changes from a rapid to practically a zero decrease, and even, as usually recorded, to a slow increase of temperature with increase of elevation, much more abruptly than one would infer from the given curves. But this more or less abrupt change varies considerably in altitude from day to day. Therefore, when a large number of actual gradients are averaged an *apparent* gradual transition is indicated.

Two other features calling for some attention are shown by the lower portion of the summer gradient; namely, the fact that through the first half kilometre the temperature decreases but slowly, and the further fact that through the second half kilometre it decreases more rapidly than anywhere else, short of very considerable altitudes. Now nearly all the observations from which this summer gradient was constructed were obtained during the early forenoon. Hence the average slow decrease of temperature with increase of elevation is the result only of ordinary morning inversions. On the other hand, the rapid decrease of temperature through the second half kilometre is expressive of the adiabatic gradient of unsaturated air that commonly exists during summer afternoons up to a level of at least one kilometre. In this case it has persisted in its upper portion throughout the night, and been modified, as explained, by temperature inversions only in its lower half.

CHAPTER IV.

THE ISOTHERMAL REGION, OF STRATOSPHERE.

OF all the conditions indicated by the temperature gradients of Fig. 15, by far the most surprising, and most difficult fully to explain, is the approximately isothermal state of the upper atmosphere. Indeed, the discovery of the fact that the temperature of the upper atmosphere changes but little with altitude, and the supplementary discovery of its physical explanation, constitute one of the most important advances in modern meteorology.

The exploration of the atmosphere by small balloons carrying meteorological instruments was suggested in 1809,[8] but the idea was first carried out by Hermite[9] on March 21, 1893, when an elevation of 16 kilometres was attained. In April, 1898, Teisserenc de Bort,[10] with improved apparatus, began at Trappes, France, a long series of frequent atmospheric soundings. Among other things, he soon found temperature records that indicated something unsuspected: either errors in the thermometers themselves or surprising temperature conditions in the upper atmosphere. However, numerous temperature records subsequently obtained by himself and many others in various countries and with different kinds of apparatus have shown that, in general, the temperature of the upper atmosphere actually does change but little with change of elevation. Indeed, as a rule, the change is so small that the whole region characterized by this approximate constancy of temperature has been called the " isothermal region." At present it is more generally known as the "stratosphere," though the older and less used term certainly is more suggestive of its distinguishing characteristic.

The height at which this region begins and its temperature both depend upon season, upon storm conditions, and upon latitude; but, while all these are important details, they are secondary to the fact that there is an isothermal region at all.

As soon as observations left no doubt of the actual existence of the isothermal region many explanations of it were proposed, but for a number of years all such suggestions proved unavailing. Finally, however, independently and nearly simultaneously, the generally accepted explanation occurred to Gold[11] of England and Humphreys[12] of America. The same subject has also been discussed at length by Emden.[13] The key to the explanation is this: The temperature of every portion of the atmosphere is determined, in part at least, by counteracting radiation—radiation absorbed and radiation emitted—and wherever these two are equal there is substantial constancy of temperature.

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[8] *Ann. Harvard Obs.*), **68**, pt. 1, p. 1.

[9] *L'Aèrophile*, 1, p. 45 (1893).

[10] *C. R.*, **129**, p. 417 (1899).

[11] *Proc. Roy. Soc.*, series A, vol. 82, 1909, p. 43.

[12] *Astrophys. Jour.*, vol. 29, 1909, p. 14.

[13] *Sitz. der K. Bayr. Akad. der Wis.*, Jahr., 1913, p. 55.

Mr. Gold's method of procedure was to take the best-known data concerning atmospheric absorption and radiation and to obtain, by the aid of suitable mathematics, a general solution of the problem. The chief difficulty in the application of this direct and elegant method, apart from the troublesome equations involved, is due to our imperfect knowledge of the necessary radiation and absorption constants. Numerical values in these particulars are not accurately known and certainly not easy to determine.

On the other hand, the solution offered by Humphreys, while not so direct, reduces the necessary mathematics to a minimum. In brief, it is as follows: Since the average yearly temperature of the atmosphere at any given place does not greatly change, it follows that the absorption of solar radiation by the earth as a whole is substantially equal to the total outgoing earth radiation, and in amount approximately equal to that which a black or perfectly radiating surface, equal in area to the surface of the earth would emit if at the absolute temperature 259° C.[14] Further, since at ordinary atmospheric temperatures water vapor, in any considerable quantity, absorbs and, presumably, also radiates substantially as does a black body at the same temperature, while dry air is exceedingly diathermanous, it follows that the planetary radiation of the earth is essentially water vapor radiation.

Now the records of sounding balloons show that at some altitude, in general about 11 kilometres above sea level in middle latitudes, the average temperature ceases to decrease with increase of elevation. Individual flights show many peculiarities that call for special explanation, but the purpose here is to consider only the general explanation of the main effect, and therefore average conditions are considered.

If, then, as is approximately true, the temperature does not decrease with increase of altitude above 11 kilometres, it follows that this must be the limit of anything like a marked vertical convection. And from this in turn it follows, since conduction is negligible, that the upper atmosphere must be warmed almost wholly by absorption of radiation, in part solar and in part terrestrial; but exactly how much of the final temperature of the upper atmosphere is due to the one source of heat and how much to the other it is not possible to say. However, there are certain facts that seem clearly to indicate the relative importance in this respect of the two sources. Thus the summer and winter gradients as given by Fig. 15 show a difference of temperature in the isothermal region of only about the amount that might be expected on the assumption that the temperature of the upper air is wholly dependent upon the radiation from the lower. That is to say, the seasonal temperatures of the lower atmosphere differ distinctly more than do those of the upper. It should be clearly kept in mind, too, that the particular seasonal gradients given in Fig. 15 were obtained at a latitude of, roughly, 50 degrees, where the number of hours of summer and winter sunshine differ greatly, and therefore where the seasonal temperature of the isothermal region, if essentially determined by absorption of solar radiation, should differ somewhat correspondingly. But, as no such great difference in these temperatures exist, it would appear that the temperature of the isothermal region must be chiefly due to absorption of long wave-length radiation given off by the water vapor and other constituents of the atmosphere at lower levels, and to only a very minor degree to the absorption of solar radiation. Hence, as a first approximation, one may consider this radiation alone, and for the lower atmosphere as it actually exists substitute the radiationally equivalent black shell at the absolute temperature of 259° C. Obviously, too, this surface, surrounding as it does the entire earth, may be regarded as horizontal and of infinite length and breadth in comparison to any elevation attainable by sounding balloons.

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[14] Abbot and Fowle, *Annals of the Astrophysical Observatory of the Smithsonian Institution*, vol. 2, p. 174.

Now consider two such surfaces, parallel and directly facing each other, with distance apart small in comparison to their width, and having the absolute temperature T_2, and let an object of any kind whatever be placed at the centre of the practically enclosed space. Obviously, according to the laws of radiation, the final temperature of the object in question will also become approximately T_2. If, now, one of the parallel planes should be removed, the uncovered object would be in substantially the same situation, so far as exposure to radiation is concerned, as is the atmosphere of the isothermal region in its exposure to the radiation from the lower atmosphere. Of course, each particle of the upper air receives some radiation from the adjacent atmosphere, but this is small in comparison to that from the lower water vapor and may, therefore, provisionally be neglected. Hence the problem, as an approximation, is to find the final temperature to which an object, assumed infinitesimally small, to fit the case of a gas, will come when exposed to the radiation of a single black plane.

In each case—that is to say, when between the parallel planes and when facing but one—temperature equilibrium is reached when the loss of energy by radiation is equal to its gain by absorption. Also, so long as the chemical nature of the object remains the same, its coefficient of absorption is but little affected by even considerable changes in temperature. Therefore, whatever the nature of the object, since it is exposed to twice as much radiation when between the two planes as it is when facing but one, it must, in the former case, both absorb and emit twice as much energy as in the latter. Or, using symbols,

$$E_2 = 2E_1$$

in which E_2 and E_1 are the quantities of heat radiated by the object per second, say, when between the two planes and when facing but one, respectively.

Again,

$$E_2 = K_2T_2^{n_2}$$

and

$$E_1 = K_1T_1^{n_1}$$

in which T_2 and T_1 are the respective absolute temperatures of the object under the given conditions, and K and n the radiation constants.

For every substance there are definite values of K and n, which, so long as the chemical nature of the object remains the same, do not rapidly vary with change of temperature. Hence, assuming $K_2 = K_1$ and $n_2 = n_1$, we have from the equation

$$E_2 = 2E_1$$

$$T_2 = \sqrt[n]{2}\;T_1$$

From this it appears that there must be some minimum temperature T_1 below which the radiation of the lower atmosphere will not permit the upper atmosphere to fall, though what it is for a given value of T_2 depends upon the value of n.

Presumably the radiation of the upper atmosphere is purely a thermal radiation, and therefore in full agreement, as is the thermal radiation of water vapor, carbon dioxide, and certain other gases, with the Kirchhoff[15] law. In other words, the ratio of emission to absorption for any given wave-length, presumably, is wholly a question of temperature, and is numerically equal to the radiation of a black body at the same temperature and wave-length. In symbols,

$$\left(\frac{He}{h}\right)_{\lambda, t} = (E)_{\lambda, t}$$

in which H is the incident energy, h the energy absorbed, and e the energy emitted by the body or gas in question at the wave-length λ and temperature t, and E the black body emission at the same wave-length and temperature, all per equal area and time.

To fix the ideas, let the body of gas under consideration be a shell one centimetre thick, surrounding the earth at a fixed distance—20 kilometres, say, above sea level—and let the black body be a very thin shell at the same temperature inside and outside, that may, if we wish, take the place of the gas shell. Now, since nearly all the incident radiation under consideration, the radiation of the earth and its atmosphere onto a shell at 20 kilometres elevation, or anywhere else in the isothermal region, comes from below, we may assume it, or its normal equivalent, to be substantially the same for all levels of the upper atmosphere, and assume the emitted radiation to be all the energy sent out by the shell on *either* or on *both* sides; only, whatever the assumption for one shell, the same must be made for the other.

Returning to a consideration of the temperature of the upper atmosphere under the influence of radiation from the lower gases: Since the composition of the upper atmosphere is not appreciably changed by a change of even 50° C., it follow that such a change of temperature will not materially alter its coefficient of absorption. Hence a change in the intensity of the incident radiation H will make substantially the same proportionate change in the rate of absorption h, whatever the alteration in temperature. In short,

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[15] Pringsheim, *Congrès International de Physique,* Paris, 1900, vol. 2, p. 127.

$$\frac{H}{h} = K \text{ a constant, presumably.}$$

Hence

$$\frac{e_{\lambda, t_1}}{e_{\lambda, t_2}} = \frac{E_{\lambda, t_1}}{E_{\lambda, t_2}}$$

or

$$\frac{e_{\lambda, t_1}}{E_{\lambda, t_1}} = \frac{e_{\lambda, t_2}}{E_{\lambda, t_2}}$$

Unfortunately, nothing is known of the spectral distribution of the energy radiation of the cold upper atmosphere, though possibly it is of the irregular, but more or less continuous broad band, type. If this is its distribution, and if for each wavelength the increase of black body radiation, for a small increase of temperature, is proportional to the total radiation at that wave length, which it is to a rough first approximation, then to about the same average approximation,

$$\frac{e_{t_1}}{e_{t_2}} = \frac{E_{t_1}}{E_{t_2}},$$

in which the symbols stand for the total radiation of all wavelengths.

But from the Stefan law in regard to the total radiation of black bodies, we know that

$$\frac{E_{t_1}}{E_{t_2}} = \frac{T_1^4}{T_2^4}$$

in which T_1 and T_2 are the respective absolute temperatures.

Hence, as explained above, if the spectral distribution of the radiation of the upper atmosphere is continuous, or nearly so (no matter how irregular), and not confined chiefly to lines with zero radiation between them, it follows that in the equation,

$$T_2 = \sqrt[n]{2}\, T_1$$

the numerical value of n must be 4, roughly. But, as already explained, the value of T_2 is substantially 259° C. absolute; hence, on the assumption that $n = 4$, it follows that $T_1 = 218°$ C. absolute. And this is the value, approximately, that observation gives.

Whatever the facts in regard to the radiation constants of the atmosphere, the laws of radiation and absorption demand that the temperature of the upper atmosphere shall change but little with change of elevation. Besides, while the exact value of this temperature—the temperature of the isothermal region—is, of course, best determined by actual observation, it also may be computed approximately from the known intensity of outgoing radiation, together with the thermal properties of the gases of the atmosphere.

Doubtless solar radiation affects the temperature of the isothermal region to some extent, but, presumably, not very much, since the radiation from the lower levels seems competent not only to produce an isothermal condition in the upper levels, but also to maintain them at substantially the observed temperature. Further, the lower atmosphere obviously is slightly warmed and its radiation correspondingly increased by return radiation from the upper, but this presumably does not affect the general validity of the above reasoning, which is based on the action of the *total* outgoing radiation.

Given the isothermal condition of the upper atmosphere, it follows that the heated surface air can, under favorable circumstances, rise till, but only till, by expansion it has cooled down to that temperature (the temperature of the isothermal region) below which the radiation from the lower atmosphere will not allow it to fall.

The existence of an upper isothermal region and the vertical temperature gradient (Fig. 15) suggest rational explanations of a number of otherwise obscure meteorological phenomena—why the clouds of a given region have a fairly well-defined maximum elevation; why this elevation is greater in summer than in winter; why it is a level of maximum cloud formation, and the like—but all these are special phenomena that will be discussed independently later on.

(*To be continued.*)

MAINTAINING PHOTOGRAPHIC STANDARDS.*

BY

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PHOTOGRAPHY is so generally practised by technical workers that it is thought a description of the methods employed for the determination and upkeep of the quality of light-sensitive materials may prove interesting. No doubt many workers have seen marked on the packages of photographic plates and films certain numbers that are intended as an indication of the speed of the emulsion. These numbers may be expressed as Hurter and Driffield, Watkins or Wynne values, and I shall endeavor in this paper to describe just how these speed readings are determined and precisely what they mean. Shortly after the introduction of the gelatine dry plate it was customary to express the speed of an emulsion as X-times, which meant that it was X-times the speed of a wet collodion plate. Such speed readings naturally had no real meaning, as they were based upon a variable factor. In the early days of dry-plate photography a well-known photographic worker, Leon Warneke,[1] introduced a sensitometer consisting of a series of numbered squares with increasing quantities of opaque pigment. The plate to be tested was placed in contact with this and an exposure made to the light emanating from a tablet of luminous paint which had previously been excited by exposure to a fixed length of burning magnesium ribbon. After development and fixation the last visible number was taken as expressing the speed of the plate.

The chief objections to this method were that no two numbered plates agreed in density, and the light emitted by the luminous surface varied considerably between its excitation and the exposure of the plate. Furthermore, the pigmented squares possessed selective spectral absorption. It is not uncommon in these days to see plates marked upon the old Warneke system. The

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* Communicated by the Author.

[1] Warneke, *British Journal*. 1881.

Seed plates—23 and 27—are instances of this. It is here implied that for the same standard exposure these two Seed emulsions would show as the last visible squares Numbers 23 and 27 respectively. Later Chapman-Jones[2] introduced a modified Warneke sensitometer with a series of 25 graduated densities, a series of four colored squares and a strip of neutral gray, all five being of the same luminosity, and a series of four colored squares, each passing a definite portion of the spectrum. This plate tester was used with a standard candle as a light-source and is still in use for rough estimations of the speed and color sensitiveness of plates. Various other methods more or less similar in principle have been tried, but none have proved practical.

In 1890, two English scientists, Doctor Hurter and Mr. Driffield, published a paper, entitled "Photochemical investigations,"[3] which dealt with the chemical, physical, and mathematical principles underlying a scientific system of testing the speed and other characteristics of photographic emulsions. Since Hurter and Driffield's time many investigators have worked on the system and contributed towards its perfection. In connection with the testing of emulsion speeds there are several terms and definitions which must be thoroughly understood. The most important are opacity, transparency, and density. Opacity is the optical property of a substance (in our case silver) to impede the passage through it of light. In other words, opacity is the supression of light or its absorption by the silver image. Transparency is the inverse of this, and is measured by that fraction of the original light which the silver image transmits. For substances which do not reflect much light, such as a thin layer of India ink or a layer of reduced silver deposited as a black substance in negatives, the relation between the quantity of the substance present and the light absorbed is quite simple. If we hold a screen in the form of a thin layer of dilute India ink between the eye and a light-source the layer of India ink absorbs light and therefore reduces the intensity of the light transmitted. Supposing that such a layer absorbs one-half of the incident light, naturally one-half of the light will be transmitted, and, whatever may be the intensity of the original light, the intensity after passing through the India-ink layer will be one-half of what it originally was. Two such layers of ink will reduce the incident light to one-fourth its original intensity, and any number of layers will reduce the intensity of the light to a fraction which is equal to the remnant of light the first layer passes, but raised to a power the index of which is the number of layers employed. Thus if n layers were employed and the first one reduced the intensity of the incident light to a fraction $\frac{1}{m}$, then n layers would reduce it to $\left(\frac{1}{m}\right)^n$. If in place of using several successive layers, the first layer is made to contain as much India ink as the n successive layers contain altogether, we shall find that the one layer has the power of reducing the intensity of the light transmitted by exactly the same amount as the n layers do. The reduction of the intensity of the original light is due to the absorption of light by the black particles, and is governed simply by the number of them which are interposed in a given area. Thus we find that the number of layers can be replaced by the number of particles, and the rule can be stated in this form—the intensity Tx of light after passing A particles of a substance is a fraction of the original intensity T, such that $\frac{Tx}{T} = \left(\frac{1}{C}\right)^A$. For mathematical reasons the fraction $\frac{1}{C}$ is generally expressed as a negative power of the base of the hyperbolic logarithms e, so $\frac{1}{C} = e^{-k}$, and we can write $\frac{Tx}{T} = e^{-kA}$. The symbol k is adopted for the coefficient of absorption, then the fraction $\frac{Tx}{T}$ represents and measures the transparency of the substance, and the inverse of this is $\frac{T}{Tx} = e^{kA}$ and measures the opacity of the substance and indicates the intensity of light that must fall on one side of the substance in order that a given intensity may be transmitted. The letter T is used to denote transparency and O opacity.

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[2] Chapman-Jones, *Photographic Journal,* 1901.

[3] Hurter and Driffield, *Jour. Soc. Chem. Ind.,* 1890.

Density is frequently confused with opacity. By density is meant the number of particles of a substance spread over a given area. In our case it is the relative quantity of silver deposited per unit area multiplied by the coefficient of absorption; kA is what is termed density, and its symbol is the letter D.

The laws of transmission and absorption in connection with a layer of India ink also hold good for a layer of reduced silver, such as exists in a negative, hence it will be seen that density as applied to photographic negatives is directly proportional to the amount of silver deposited per unit area and may be used as a measure of that amount. The relations existing between the three terms, opacity, transparency, and density, are as follows:

$$O = e^D$$
$$T = e^{-D}$$
$$D = \log_e O = -\log_e T.$$

In theoretical considerations, such as those dealt with above, Napierian logs are used, but in practical sensitometry common logarithms are used. The full relation existing between opacity, transparency, and density, and also the terminology generally adopted in practical sensitometry, are shown in Fig. 1. By a consideration of these definitions we are in a position to trace the connection between the densities of a theoretically perfect negative and the light intensities which formed them. Density is the logarithm of the opacity, and since, in a theoretically perfect negative, opacities are directly proportional to the intensities of the light which produced them, it follows that each density must be proportional to the logarithm of the light intensity which produced it, or, more correctly, density is a linear function of the logarithm of the intensity of light and time of exposure. Therefore, in a theoretically perfect negative the amounts of silver deposited in the various parts are proportional to the logarithm of the intensities of light proceeding from the corresponding parts of the original object. The practice of a system of emulsion speed measuring is based on the inter-relation of the before-mentioned definitions. To apply these practically in plate-speed measurements four instruments are required:

1. Some form of standard light for making the exposures.
2. An exposing machine used in conjunction with the standard light for impressing the plates with a series of known exposures.
3. A thermostat for maintaining the developing solutions at constant temperature.
4. Some form of photometer for reading the densities of the plates made in the exposing machine.

Standard Lights.—Hurter and Driffield, in their investigations, used the English standard candle. The great objection to this is its spectral composition; candle light is decidedly orange-red; for non-color sensitive plates this may be used, but with yellow or red sensitive plates the speed readings obtained would be absolutely wrong. The readings would be five or six times the true speed. In Germany the Hefner amyl-acetate lamp is generally used; in England the Vernon-Harcourt pentane lamp. Undoubtedly the most satisfactory light-source is acetylene; a special burner is used giving a long, cylindrical flame. The burner is surrounded by a circular metal chimney which has a small, rectangular opening fitted with a cone that extends to within three millimetres of the surface of the flame; thus only a small portion

FIG. 1.

$$O = \frac{\textit{Intensity Incident Light}}{\textit{Intensity Transmitted Light}} = \frac{I}{I_t}$$

$$T = \frac{\textit{Intensity Transmitted}}{\textit{Intensity Incident}} = \frac{I_t}{I}$$

$$D = -\log_{10} T = \log_{10} O$$

$$I \div O = I_t \text{ or } I \div I_t = O$$

Putting $\frac{I}{I_t}$ into logs gives

$$\log I - \log I_t = \log O = D = \textit{Density}$$

For instance when a plate transmits half the incident light.

$$I \div I_t = \textit{Opacity}$$

$$100 \div 50 = 2$$

$$\text{Log } I - I_t \log = \log O = \textit{Density}$$

$$\begin{array}{r} \log 100 = 2.000 \\ \log 50 = 1.699 \\ \hline 0.301 = D = \textit{Density} \end{array}$$

I		I_t	T	O	D
100		100	1	0	0
100	░	10	.1	10	1
100	▒	1	.01	100	2
100	▓	.1	.001	1000	3

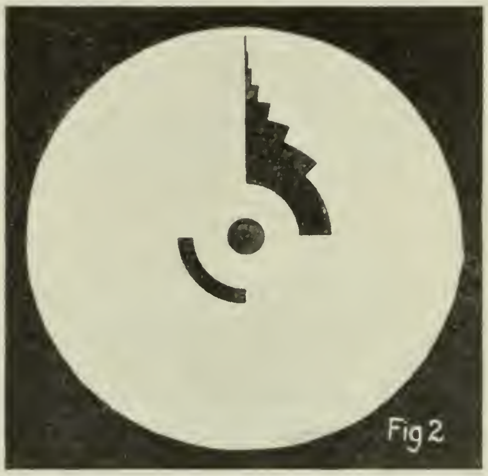
$$\log I - D = \log I$$

$$\log I_t + D = \log I.$$

of the flame is used, and by always keeping the gas pressure constant by means of a manometer, and the height of the flame the same, the intensity of the light does not vary one per cent. This acetylene light is calibrated to a standard candle. In front of the rectangular opening in the metal chimney is placed a special blue-violet filter that reduces the spectral composition of the acetylene to practically the same as daylight.

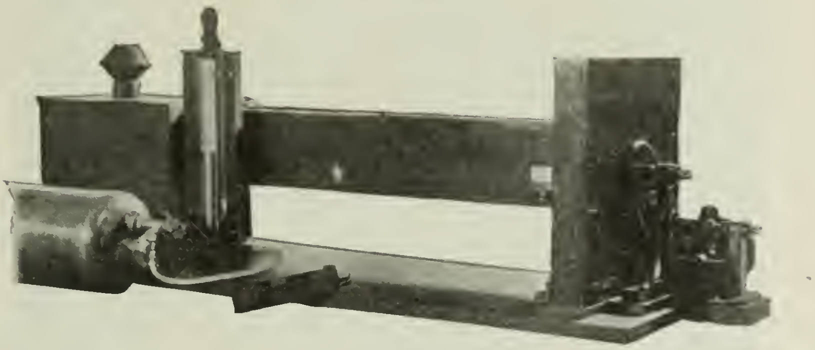
Exposing Instruments.—Various instruments for impressing a graduated series of exposures on a plate have been proposed, and they may be divided into two classes, depending on whether a time or an intensity scale is used. Intensity scales usually consist of a sheet of glass covered with squares of pigmented gelatine transmitting known amounts of light; thus in the Warneke sensitometer previously described each square transmits one-third less light than the preceding. The Chapman-Jones sensitometer is another example of an intensity scale; in practical sensitometry intensity scales are seldom used. Time scales may be impressed by intermittent or continuous exposure. For many reasons continuous exposures are most to be desired, but in practice it has been found difficult to construct a suitable instrument. A time scale impressed by intermittent exposure is easily obtained with a sector wheel having a series of angular openings of the following values: 180, 90, 45, 22.5, 11.25, 5.625, 2.812, 1.406, and 0.703 degrees; each aperture passes twice as much light as the preceding one and gives double the exposure. The sector wheel

FIG. 2.



is revolved during the exposure in front of, and as near as possible to, the sensitive plate. For negative emulsions it is usual to expose for 40 candle-metre-seconds, and, as the largest angle on the wheel is 180 degrees, it is obvious that an exposure of 80 c. m. s. must be given to obtain an effective 40 c. m. s. The form of the wheel is shown in Fig. 2. In order to do away with the inconvenience of working in a dark room and to avoid troublesome reflections, the sector wheel is enclosed in a box 12 inches by 12 inches by 2 inches. At the back of the box are fitted grooves to carry the plate-holder. The complete instrument is shown in Fig. 3. A pulley is provided by means of which the wheel can be rotated during the exposure of the plate; a small 1/15-horsepower motor geared down to 50 revolutions a minute is used.

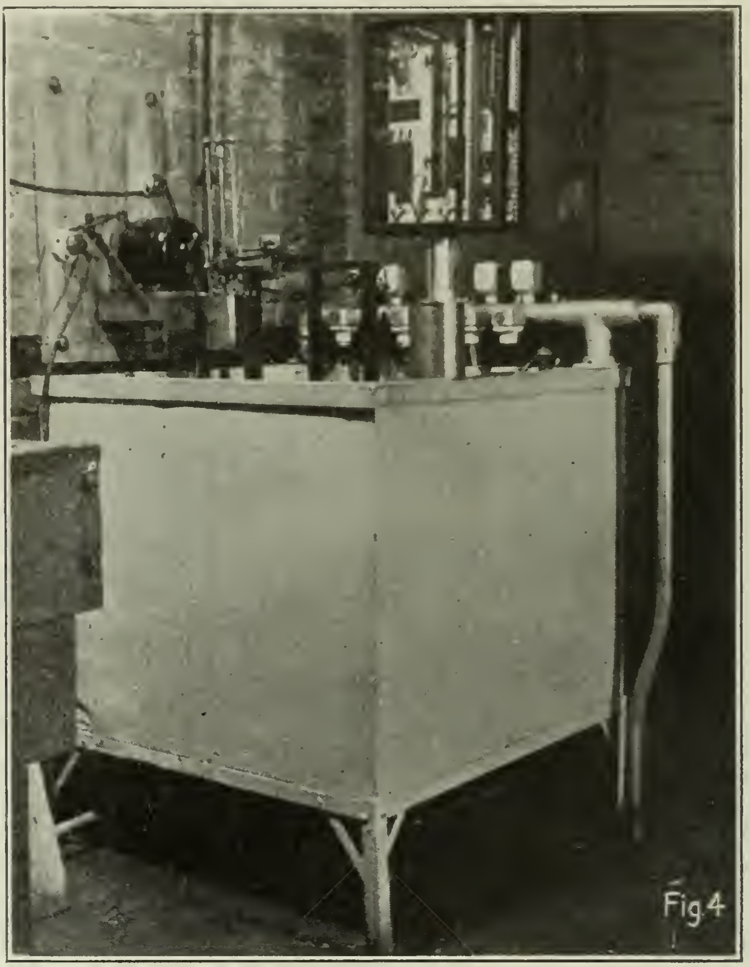
FIG. 3.



A box 6 inches by 6 inches by 33 inches contains an exposing shutter actuated by a milled head, and grooves are provided for two fluid cells by means of which light of any color can be obtained. The special acetylene burner before described is fitted on a stand having a vertical and horizontal movement by rack and pinion, so that the light itself may be placed at one metre distance from the plate surface and exactly centred. The acetylene tank, manometer, and lamphouse are also shown in the illustration. In practice two plate-holders are used—one for two plates 4¼ inches by 1 inch, the other for one plate 4¼ inches by 1½ inches; this latter holder is arranged so that two series of exposures can be impressed on the same plate. In each plate-holder only a narrow strip of the plate is exposed; the unexposed portion is used as a fog strip.

Thermostats.—The thermostat in use is a modified form of the Freas water thermostat and has proved very satisfactory.[4] The complete installation is shown in Fig. 4. The thermostat tank has a capacity of 340 litres of water and is equipped with a paddle-stirring device and mercury regulator which controls the electric heaters through a thermal relay. Hot point tubes are used as the source of heat. There are devices for maintaining the water at constant level and for cooling the water in the tank when the room temperature is too great. A special top is fitted to the instrument with developing cups set down into the water, and the plate strips to be developed are held in small metal slides

FIG. 4.



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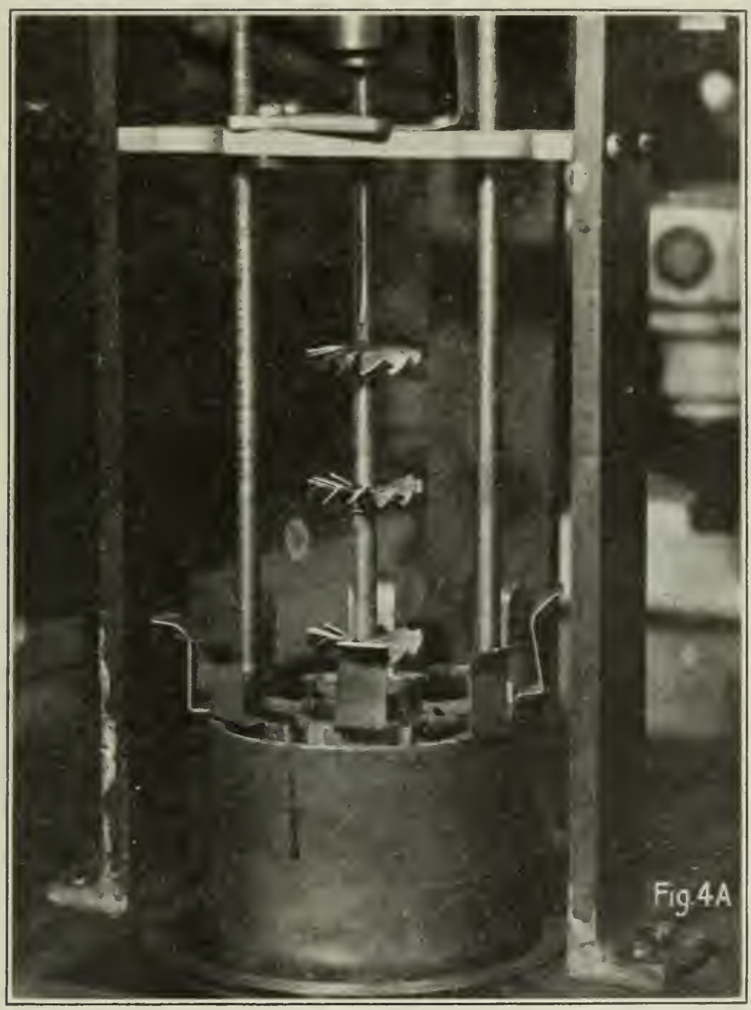
[4] Hitchins and Gilbert, "A Water Thermostat for Maintaining Photographic Developing Solutions at Constant Temperature," *Photo. Jour. of America*, 1917, 139.

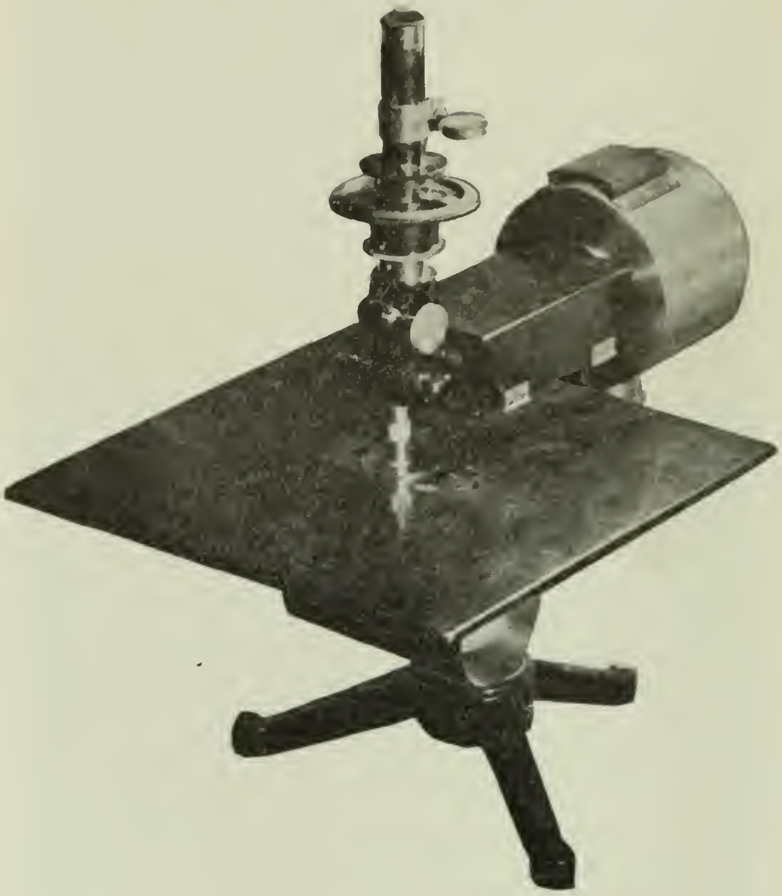
which fit around the inner periphery of the cylinder entering into the cup. Housed in an inner cylinder there is a small multiblade paddle which pulls a steady stream of developer from the bottom of the developing cup and discharges it over the top of the cylinder, distributing it evenly over the plate strips. Fig. 4*A* shows this portion of the thermostat in detail. As the various development times are completed the plate strips in their holders can be withdrawn and placed in the fixing bath without being handled with the fingers. The accuracy of this thermostat is within one two-hundredth of a degree plus or minus, and it will run unattended day in and day out. For accurate results in sensitometry it is of vital importance that the temperature of the developer be constant.

FIG. 4A.



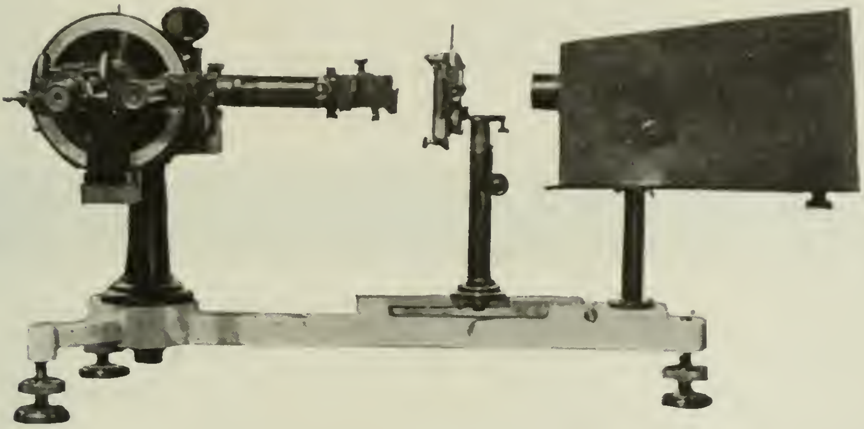
Photometers.—A photometer as used in photographic work is an instrument for measuring the absorption of light by various media. Hurter and Driffield, in their original investigation, used the old Bunsen grease-spot photometer, a form not really suitable for photographic measurements. Polarization or spectro-photometers are now generally used in sensitometric work. The Martens polarization photometer is an excellent instrument and gives very accurate readings. In this photometer extinction is obtained by means of a Wollaston prism. The formula for converting the readings to densities is $\log.\tan.^2\theta^1 - \log.\tan.^2\theta$ in which θ^1 is the angle or degree of rotation with the negative density in position and θ the angle without the negative density or the zero of the instrument. This photometer is illustrated in Fig. 5. Recently a Hüfner spectro-photometer built by Adam Hilger, of London, has been used. This instrument is designed for the accurate measurement of the absorption of liquids or dyes at any

FIG. 5.



wave-length, and for the determination of the densities of photographic plates or films, for which purpose it is extremely convenient and accurate. Supposing it is desired to compare the intensities of two beams of light, one of which has undergone absorption by passage through a photographic plate, for instance: in the path of the beam which has not undergone absorption is interposed a Nicol prism which polarizes the light perpendicularly. The two beams of light are then thrown on the slit of the spectroscopic portion of the instrument, being brought into close juxtaposition with a sharp dividing line by a prism of special design. The light, after passing through the slit, undergoes collimation and is dispersed into a spectrum by a prism, and after passing through a second Nicol prism is brought to a focus and observed by an eye-piece. Two spectra are then seen, one above the other, the one being an absorption spectrum of the substance under observation, the other spectrum being reducible by rotation of the second Nicol prism to any desired intensity. The intensity of this latter spectrum can be deduced from the rotation of the second Nicol, and thus by exact matching of any desired part of the two spectra an exceedingly accurate measurement of the amount of absorption by the material under observation can be obtained. The Hilger instrument is shown in Fig. 6. The intensity of light passing through crossed Nicols is proportional to the square of the cosine of the angle θ between them, and the formula for converting the readings to densities is as follows:

FIG. 6.

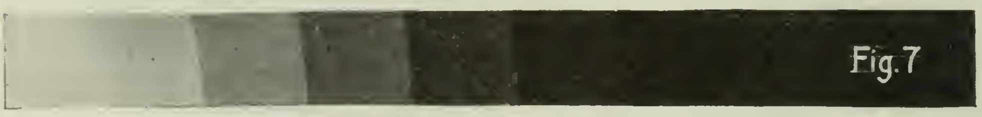


$$\text{Density} = -\log._{10}\cos.^2\theta$$

With this instrument transparency = $\cos.^2\theta$, and opacity = $\frac{1}{\cos.^2\theta}$.

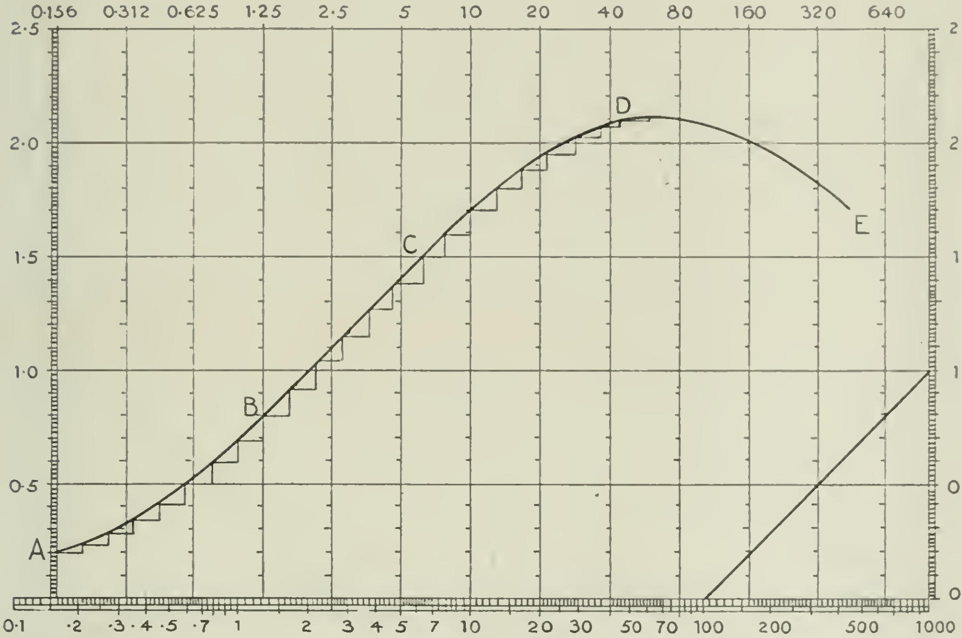
In practice the system of plate-speed measuring is carried out as follows: The acetylene light is lit; the height of the flame and gas pressure adjusted; the light should burn at least five minutes before any exposures are made, so that it may have time to settle and burn steadily. The plate-holder is loaded with two strips of the film or plate to be measured. The strips lie side by side and are exposed together in the exposing machine. Then the plate-holder is inserted in the exposing instrument, the sector wheel set revolving, the shutters of the plate-holder drawn, and exposure made by means of the flap shutter. The candle-power of the acetylene light must be known so that an exposure equivalent to 40 c. m. s. can be given, then the strips are developed for times t^1 and t^2 in such ratio that $t^2 = 2t^1$ in the thermostat at 65° F. Practically any developer may be adopted as the standard, but potassium bromide must not be added for plate-speed work. The time of development is merely a matter of convenience; if too short, the densities are thin, and if too long, the higher densities are hard to read. Time of development does not affect the speed readings obtained. As soon as developed the plate strips are plunged in clean hypo, and when completely fixed are well washed and immersed in a 5 per cent. solution of hydrochloric acid for a few minutes to dissolve any lime salts that may be deposited in the film. The strips are then allowed to dry naturally. The negative obtained is shown in Fig. 7. One edge has been left unexposed and is called the fog strip. From this is measured the inherent fog in an emulsion, viz., the density of the gelatine, the glass, or celluloid, and any silver reduced without light action. The series of graduated densities are now measured with the photometer and the results minus fog reading plotted in the form of a curve upon a special chart. Hurter and Driffield called this the "Characteristic Plate Curve," because they found that with all plates under certain conditions of exposure the curves obtained were of the same character. The curve is always of an ∫ shape, and if the plate has been sufficiently exposed may be divided into four regions (see Fig. 8), the concave

FIG. 7.



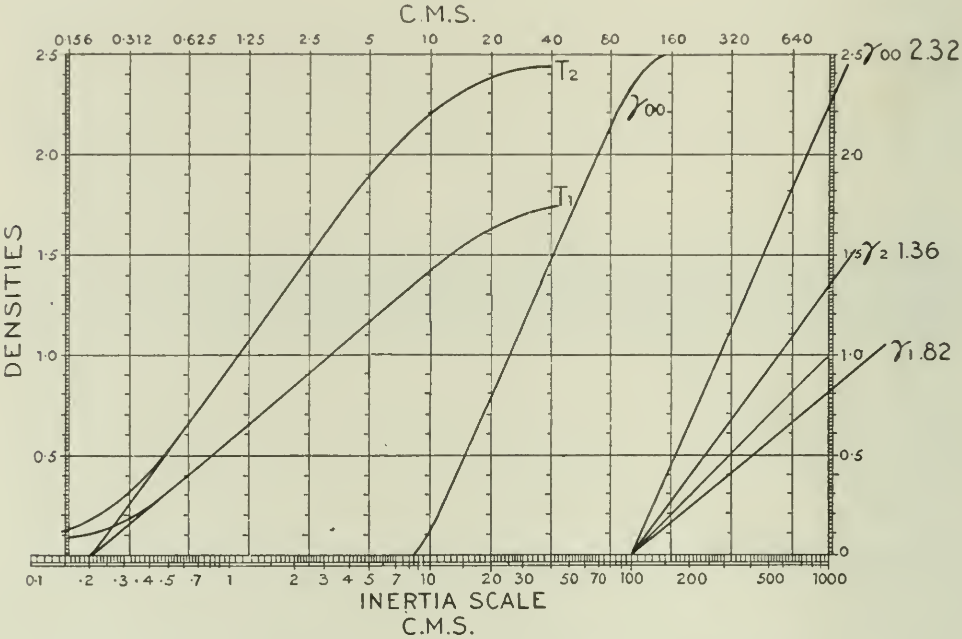
part *A-B* corresponding to under-exposure; the straight line period *B-C* corresponding to correct exposure; the convex part *C-D* denoting the over-exposure period; and the last period of the curve, *D-E*, corresponding to reversal. Suppose we compare this typical curve to a flight of stairs: it will be seen that in the under-exposure period the steps show a gradually increasing rise; keeping in mind that each step means growth in density, it will be seen that we have here an absolutely false relationship. In this case proportionality exists between exposure and density instead of between exposure and opacity. A negative, the gradations of which fall within this period, will have strong contrasts and be recognized as under-exposed by the practical photographer. The shadows and nearly all half-tones will be represented by almost bare glass, and the high lights will be of relatively extreme density. In the period of correct exposure the steps are all of equal rise; that is to say, each doubling of the exposure is represented by an equal gain in density, so that a negative the gradations of which fall within the period of correct exposure differs as little as possible from that which at the beginning was defined as theoretically perfect. It will be remembered that the definition of a perfect negative was that the densities of the negative should be proportionate to the logarithm of the exposures which produced them, and it is characteristic of the straight-line period of the curve

FIG. 8.



that the densities are proportionate to the logarithms of the exposures. As the result of many measurements of the densities falling within this period it has been found that the straight line portion conforms to the following simple linear equation: $D = \gamma (\log. E - \log. i)$, D being the density, γ a constant depending on time of development; E the product of intensity of light and time or the "exposure," and i a constant depending upon the speed of the plate. The over-exposure period is marked by a gradual decrease in rise in the steps, which finally become almost imperceptible. In this period the densities, instead of growing with increase of exposure, steadily decrease. A negative, the gradations of which fall within this period, will be equally as false as one in the under-exposure period, but in an opposite direction. Under-exposed negatives show too much contrast; over-exposure yields a flat, thin negative. In the last period of the curve *D-E* there happens the phenomenon reversal; this is the transformation of the negative into the positive. This period is mainly of theoretical interest; such long exposures are required to produce true reversal that in ordinary photographic practice this period is negligible.

FIG. 9.



Before proceeding further it will be as well to describe the chart on which the curves are plotted. It is shown in detail in

Fig. 9. The top line of figures stand for exposures in c. m. s. The figures at the left-hand side represent densities; the bottom line of figures constitute the inertia scale which is used in determining the plate speeds. The right-hand set of ordinates are gammas and represent actual degrees of contrast in the negative. From 100 on the inertia scale there is a printed line travelling to γ 1.0, which will be explained later. To obtain the speed of a plate the straight-line portion of the curve is prolonged until it cuts the inertia scale; this point is called the inertia; then $34 \div i =$ the speed of the plate. This constant 34 holds good only when the standard light is equivalent to a standard candle. In the example shown in Fig. 9 the inertia is 0.2 and the speed is 170. The inertia is really a measure of the least exposure which will just mark the beginning of the straight line or correct exposure period. The speed of an emulsion is the inverse value: The longer the exposure required to bring a plate to the beginning of the correct exposure period the slower the emulsion. Inertia is really an exposure expressed in c. m. s.

In all plate-speed testing it is essential that two strips of the plate are exposed together; then one strip is developed for t^1 and the other for t^2; that is to say, one strip is developed twice as long as the other. The two series of densities obtained are read on the photometer, and the two curves plotted on the same chart. It will be seen that, although one strip was developed twice as long as the other, the inertiæ coincide, both straight-line portions when prolonged cutting the scale at 0.2. When we have plotted the t^1 and t^2 curves of any plate we can read not only the speed but can obtain in addition a lot of useful data relating to the character of the emulsion. We can show graphically the amount of contrast that any particular emulsion will give for a given time of development. This is done by drawing parallel with the straight-line portions of the curves t^1 and t^2, lines from 100 on the inertia scale until they cut the γ scale. Curve t^1 will then give γ^1 and t^2 will give γ^2. Supposing the times of development for t^1 and t^2 to have been 3 and 6 minutes, it will be seen that γ^1 and γ^2 represent graphically the degrees of contrast and density obtained in 3 and 6 minutes' development. Whenever the γ line of the plate coincides with the printed γ line of the chart the contrasts of the subject photographed are correctly rendered. If the reading is below 1 the contrasts of the subject are reduced, and if above 1 are increased. Having found γ^1 and γ^2, $\gamma\infty$ is easily determined. $\gamma\infty$ is a very important factor; it measures the ultimate contrast and density obtainable with a given emulsion. $\gamma\infty$ can be determined by direct development; a strip of the plate to be tested is exposed as usual to a graduated series of light intensities and then developed for 45 minutes, the densities read and the curve plotted. A parallel to the straight-line portion of the curve is drawn from 100 on the inertia scale to the γ scale, and where it cuts is taken as $\gamma\infty$. In the example shown (Fig. 9) $\gamma\infty = 2.32$. $\gamma\infty$ can also be calculated mathematically from the figures obtained for γ^1 and γ^2; the formula is as follows:

$$\infty = \frac{\gamma 1^2}{2\gamma 1 - \gamma 2} = \frac{\cdot 82^2}{2(\cdot 82) - 1\cdot 36} = \frac{6724}{2800} = 2\cdot 40$$

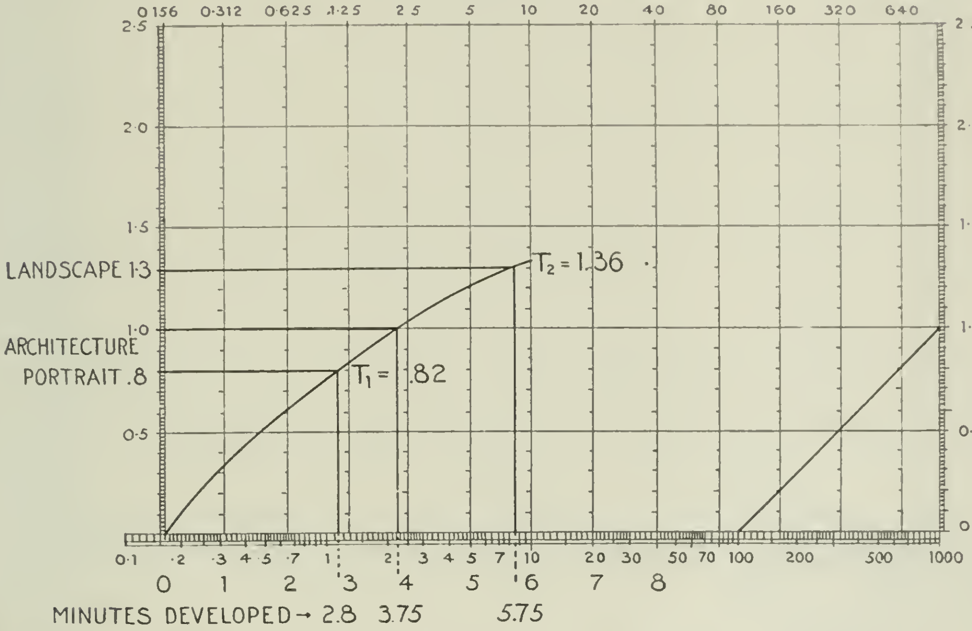
For $\gamma\infty$ by direct development 2.32 was obtained, and 2.40 by calculation. In connection with the character of photographic emulsions there is another important factor—*K*, or the velocity constant; this is the speed with which a plate develops. It is arrived at in the following manner:

$$K = \frac{1}{t}\log_e \frac{\gamma^1}{\gamma^2 - \gamma^1} = \frac{1}{3}\, 2\cdot 3026 \times \log_{10} \frac{\cdot 82}{1\cdot 36 - \cdot 82}$$

$$K = \frac{1}{3}\, 2\cdot 3026 \times \log_{10} 1\cdot 52 = \frac{1}{3}\, 2\cdot 3026 \times \cdot 1818 = \frac{1}{3} \cdot 43881 = \cdot 1463$$

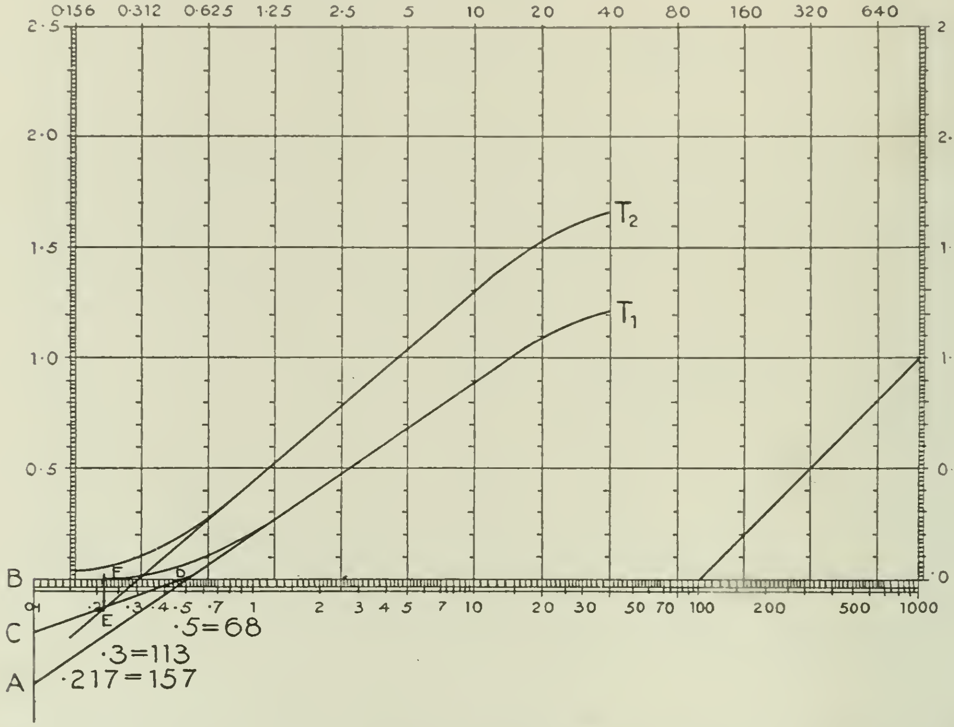
K depends upon the plate, the developer, and the temperature of the developer. It increases as the concentration of the developer is increased, so that in making measurements of *K* it is important that the developer be kept constant. *K* is usually higher in a slow plate than in a fast one, and decreases as the plate ages. For many purposes a plate with a high $\gamma\infty$ is very useful. It means that with under-exposure development can be forced and density piled on easily. In this case density-giving power is equivalent to speed. It has been previously stated that when the plotted γ line coincides with the printed γ line on the chart the contrasts of the subject photographed are truthfully rendered. It is well known that for different classes of work a soft, normal, or contrastive negative may be desirable. It is an easy matter to produce a negative of the degree of contrast judged to be most suitable. This is simply the control of γ. γ is entirely dependent on length of development for a given plate, and it is easy to determine the time of development necessary to reach a given γ. It has been found that a γ or contrast of 0.80 is most suitable for portraiture where softness and modelling are important, and that for architecture a γ of 1.00 is suitable. For landscape work a γ of 1.30 has been found best. Knowing γ^1 and γ^2 for a given plate, the time of development necessary to reach a chosen γ can be shown graphically. The construction is illustrated in Fig. 10. Supposing γ^1 to be 0.82 and γ^2 1.36, use an ordinary H. & D. chart and call the base-line divisions "Minutes of Development" and the left-hand ordinates "Gammas"; then there are three points through which a curve can be drawn—0, 0.82, and 1.36. γ^1 was obtained with 3 minutes' development and γ^2 with 6 minutes', therefore the density corresponding to γ^1 is plotted on the 3-minute line, and the density of γ^2 on the 6-minute line. To find the time of development for gammas of 0.80, 1.00, and 1.30, horizontal lines are drawn from those points on the left-hand scale, and where they cut the curve a perpendicular is dropped to the base line. In the examples shown a γ of 0.80 is obtained with 2.80 minutes' development, γ 1.00 in 3.75 minutes', and γ 1.30 in 5.75 minutes' development. There is another advantage in exposing two strips of the plate together, because when the two curves are plotted it is at once

FIG. 10.



seen if free bromide is present in the emulsion or if bromide has been added to the developer. Suppose that on plotting the two curves we find that they run more or less parallel to each other and that the inertiæ do not coincide as shown in Fig. 11: this proves that there is free bromide in the emulsion, or that bromide has been added to the developer. The presence of bromide actually lowers the speed of a plate for a given time of development, so both the inertiæ obtained are wrong, the influence of the bromide not having been overcome. The way to find the true inertia is to prolong the straight-line portion of t^1 curve below the inertia scale, then from any point *A* draw the ordinate *A-B*. Bisect *A-B* at *C* and join *C-D*, the latter being the point where curve t^1 cuts the inertia scale. Continue the straight portion of curve t^2 until it cuts *C-D*, then from *E* erect a perpendicular *E-F* until it cuts the inertia scale, and this point 0.217 is the true inertia of the plate and the speed is 157, whereas the speed obtained from t^1 curve gave 0.5 inertia, equivalent to 68, and t^2 gave 0.3 inertia, equivalent to a speed of 113. It will be seen that this construction is merely a mathematical anticipation of the true speed of the emulsion that will be obtained if develop-

FIG. 11.

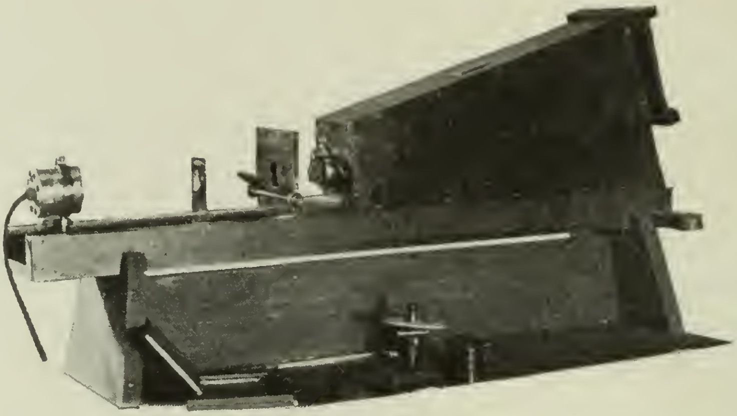


ment is continued sufficiently long to overcome the restraining action of the bromide.

Another very important property of a plate is its latitude. This can be judged fairly well from a straight-line portion of the plate curve. Supposing the straight-line portion extends from 1.25 c. m. s. to 20 c. m. s., then any exposure ranging from 1 to 16 would be in the period of correct exposure. Latitude is really the measure of the opacity of the unexposed plate to blue-violet light and can be determined more accurately as follows: A plate of known speed is exposed behind the plate the latitude of which is to be measured. For instance, suppose a plate with a speed of 150 is exposed behind an Ansco film, and, when the densities are read and plotted, gives a speed of 100, then 150 minus 100 = 50, which is the latitude of the Ansco film, because the Ansco emulsion, being sensitive to blue-violet light, cuts out or absorbs this from the standard light, and that portion of the light which passes through the Ansco film is not absorbed and so cannot do any work but it will act upon the plate behind and the densities and speed obtained under these circumstances are a measure of the non-absorption of the blue-violet by the Ansco film.

The Hurter and Driffield system, if properly carried out, is of the greatest help in maintaining a standard of emulsion quality, and in its wider and deeper applications is almost indispensable to the emulsion maker for graphically recording the effects of various experiments. It will be readily understood how changes in an emulsion during manufacture will be shown in the curves when plotted. What these variations in the plotted curve mean to the emulsion maker would entail a thorough discussion of the theory and practice of emulsion making, which is not possible in an article of this nature. In the various branches of photographic work it is necessary to use emulsions of different character. In process and copying work a slow plate having good latitude and a high $\gamma\infty$ is desirable. It should develop quickly and be capable of giving great density and contrast, and it is important that the inherent fog of the emulsion should be low. An emulsion intended for the general run of hand camera work where most of the results are underexposed should have a high speed, develop rather slowly, and have a reserve density and contrast-giving power. The under-exposure period should be well defined, and it is desirable that the emulsion be yellow-green sensitive, or, in other words, orthochromatic. An emulsion intended for portraiture should have a very high speed around about 250 H. & D. It should develop slowly, and the $\gamma\infty$ should not be higher than 2.00. It should have good latitude and a well-defined under-exposure period. In the modern practice of portraiture the tendency is to use a rapid orthochromatic or panchromatic emulsion. The inherent or chemical fog of any emulsion must be kept as low as possible. This is one of the problems of emulsion making. The inherent fog of any emulsion should not be higher than 0.20, even when the plate is developed to $\gamma\infty$. The speed readings obtained can be used directly as a basis for the calculation of exposure, because, providing two plates of different kinds are impressed with the same series of known exposures by the same light-source, their speeds are inversely proportional to their respective inertiæ; for instance, if strips of plates *A* and *B* are impressed with the same series of graduated exposures by the sector wheel, and the inertia of *A* is found to be 0.2, while the inertia of *B* = 0.4, then the speed of *A* is twice that of *B*. If the speed of *B* is 85 H. & D., then the speed of $A = \frac{85 \times .4}{.2} = 170$ H. & D.

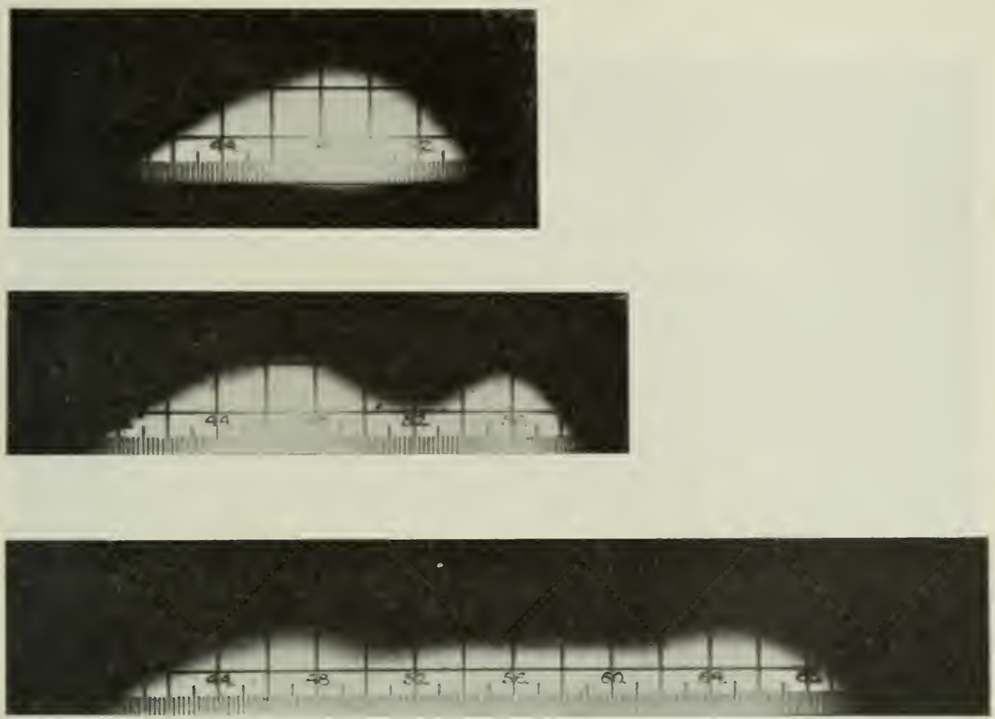
FIG. 12.



There are one or two other applications of the H. & D. system that are of use in practical photography. For instance, if we have to test a set of developers for their density-giving or reducing properties, a series of strips of the same emulsion are exposed and these strips developed in the different developers or combinations of them. When the strips have been read their curves will show graphically the performance of the various developing agents. For estimating the action of the various intensifiers and reducers a number of strips are exposed and their curves plotted, then if any of the plate strips are submitted to the action of an intensifier or reducer the difference between the curve obtained after treatment and the first curve is an indication of the action to which the plate has been subjected.

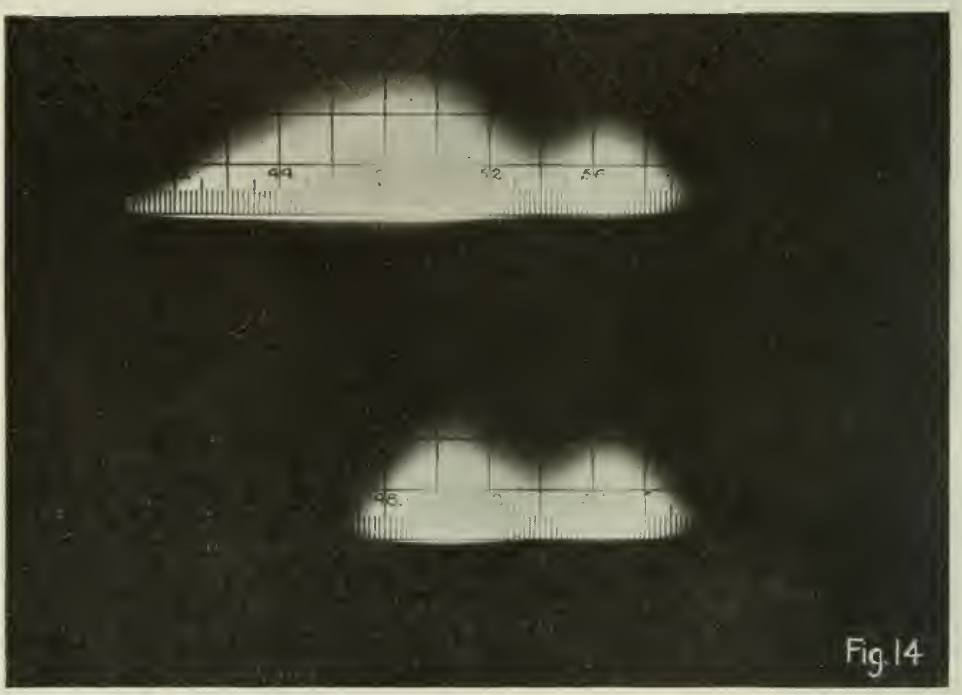
Apart from the determination of the speed, fog, gamma infinity, and velocity constant of emulsions, there is another very important factor which must be considered: this is color sensitiveness. To determine this, a Hilger diffraction grating spectrograph is used. This instrument is designed so as to project and bring to a focus in the image plane a diffraction spectrum much as any image is brought to a focus on an ordinary camera. The complete instrument is shown in Fig. 12. The plate-holder is 3¼ by 4¼ inches, and has fitted into it an accurately engraved wave-length scale. The plate to be tested is exposed behind the wave-length scale to the action of the spectrum. The spectroscopic slit has in front of it a black glass wedge that produces a

FIG. 13.



gradient of exposure across the width of the spectrum so that we obtain a negative that shows graphically the color-sensitiveness curve of the emulsion. This automatic curve plotting is due to the wedge. If a plate is very sensitive to a certain color, that color will stand more damping down by the wedge before its power to impress the plate is lost than will a color to which the plate is not so sensitive, and so the maximum or peak of the curve represents the wave-length to which the plate is most sensitive. The results obtained are illustrated in Fig. 13; the top curve is the usual one given by non-color sensitive emulsions.

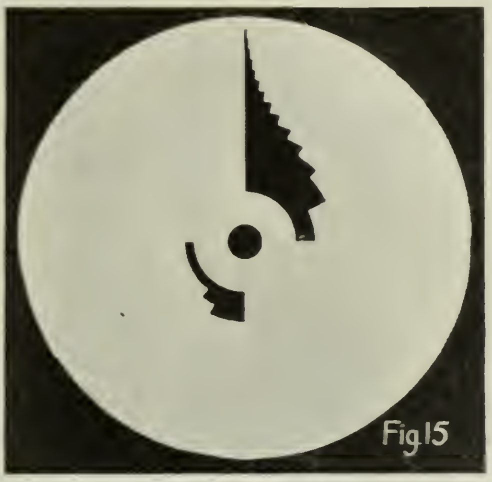
FIG. 14.



Its maximum is at wave-length 4900 in the blue, and it is quite insensitive to yellow. The second curve is characteristic of an orthochromatic or color-sensitive emulsion. A maximum still exists in the blue, but in addition there is a secondary maximum at 5600 in the yellow. This additional color-sensitiveness is obtained by adding a dye—erythrosine—to the emulsion during manufacture. The presence of the dye gives to the emulsion the power of absorbing yellow light instead of passing it, and the light so trapped is used in forming a developable image. The third curve is typical of a panchromatic emulsion.

There is an almost equal sensitiveness throughout the spectrum. In panchromatising an emulsion two dyes are usually used—pinachrome and pinacyanol. It is not usual to incorporate these dyes with the emulsion during manufacture, but the finished plates are bathed in a solution of the dyes. The first two curves show the importance of orthochromatism. A non-color sensitive plate will render even dark blue as white and light yellow as black, in absolute contradiction to the visual effect. It cannot well be otherwise, since the greatest sensitiveness of an ordinary plate is in the blue, and there is no record made of anything yellow, so yellow must be rendered as black and blue as white in the final print. An orthochromatic emulsion giving a curve like No. 2, having a secondary maximum in the yellow, will give a better rendering of color luminosity, but not a really true rendering, because the blue sensitiveness is still predominant. How to obtain true color correction by the use of a yellow screen is shown in Fig. 14. The first curve is characteristic of an unscreened orthochromatic emulsion with maximum sensitiveness in the blue. The second curve shows the effect of exposing through a screen having a multiplying factor of five. The action of the blue has been curtailed, and colors will now be rendered in practically their correct values. The maxima have been shifted, so that blue, blue-green, and yellow will be rendered as they appear visually.

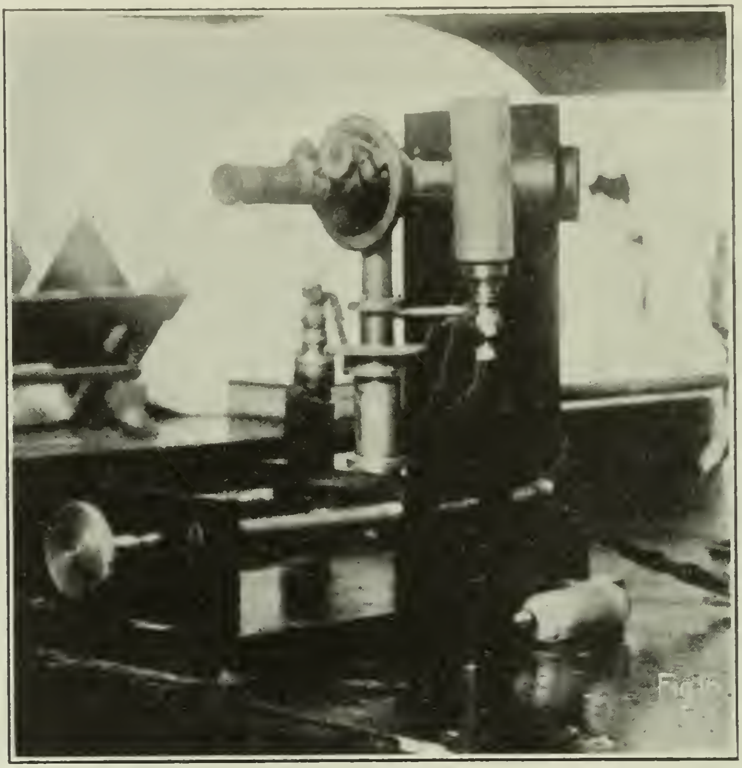
FIG. 15.



All of the foregoing discussion has been in connection with negative emulsions, but recently a modification of the plate-testing system has been applied to the determination of the character of developing-out paper emulsions.

For this work a sector wheel is also used for producing a known series of exposures; the form of the wheel is shown in Fig. 15. There are 16 sectors increasing in value as powers of the square root of 2. Geometric step-up in exposure is not practical for paper emulsions; such steps are too widely separated to reveal the delicate gradation scale. The exposing instrument used in this work is practically the same as that for negative emulsions, but in order to keep exposure within reasonable limits a 15-candle-power electric glow lamp is used, controlled by a potentiometer. The paper strips are developed at standard temperature, and after drying are read in a specially designed photometer. When reading paper deposits we are, of course, dealing with differences in reflecting power, which vary according to the amount of silver reduced. In devising a photometer for reading reflection densities precautions must be taken to avoid specular reflection or polarization of light at the surface of the

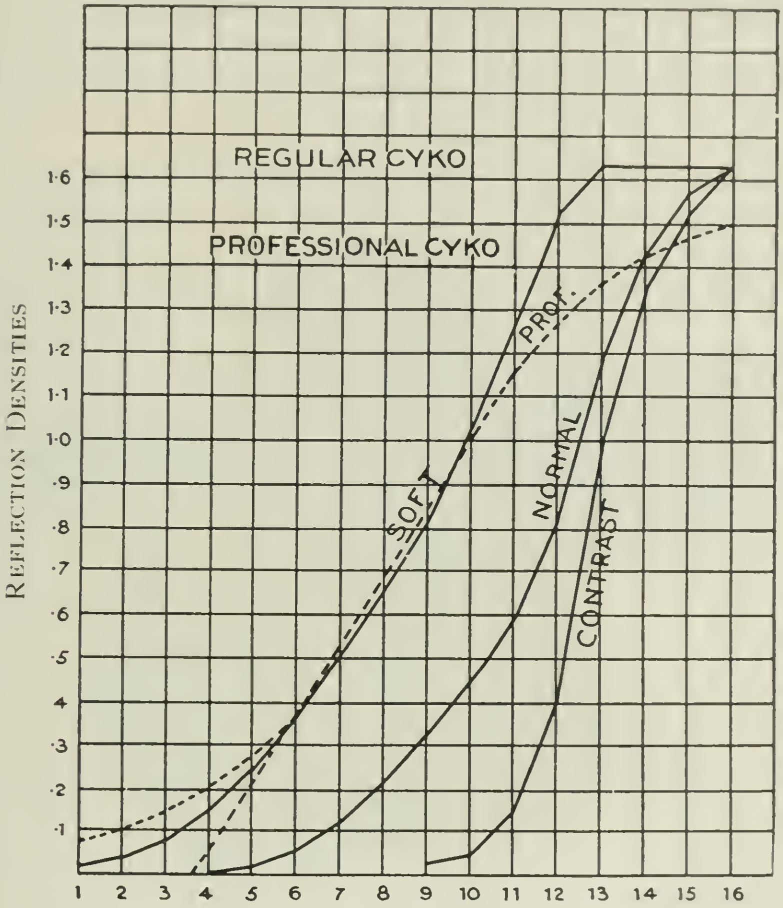
Fig. 16.



paper. The photometer in use for this purpose is illustrated in Fig. 16. The strip of graduated densities is illuminated with 45-degree light, and the tube of the instrument is at right angles to the paper surface. The photometer is a modification of the Martens instrument.

In Fig. 17 the curves obtained with the various grades of Cyko paper are shown. The curve given by Contrast Cyko is characteristic of this emulsion and shows the short scale and steep rise of a paper of this type. Normal Cyko has a longer scale and less steep rises in density. Soft Cyko and Professional Cyko give curves that are characteristic of their performance.

FIG. 17.



The paper-measuring system has been in use only a short while for determining and maintaining a standard of quality in developing-out paper emulsions. There is, however, every indication that it will prove as useful as the system of plate-speed measurements has in the control of negative emulsions.

BINGHAMTON, N. Y., May, 1917.

Common Misconception on Pistol Shooting. A. P. LANE. (*New York Sunday American*, 1914. Issued by Colt's Patent Fire Arms Manufacturing Company, Hartford, Conn.)—Pistol shooting—and, for that matter, all kinds of shooting—is the subject of more misconception on the part of the public or layman than any other sport extant. It is popularly supposed that a pistol in the pocket or within easy reach is a protection, quite without regard to the possessor's ability to use the weapon properly. As the average man uses a pistol it is not effective more than ten feet from the mark. At that distance, if the arm wavers a half inch, as is quite likely, because of the sudden jerk on the trigger—a fault characteristic of the novice—that the bullet will not touch an assailant at all. Skill in shooting does not require phenomenal ability. Any man can become a fair marksman by application and practice. Training is unnecessary; the best shooting can be done by a man in his ordinary normal condition.

To the uninitiated, an expert pistol shot holds the gun out with a steady hand, gets it right over the bull's-eye, and pulls the trigger. Nothing could be further from the fact. The pistol shooter cocks the gun with the thumb, holds it out toward the target with his arm extended straight, takes aim, begins gradually to pull the trigger, watches the gun weave back and forth across the mark, and, when it is in the middle of one of its trips across the bull's-eye, finishes the pull of the trigger. There is no such thing as holding a pistol immovably over a bull's-eye and shooting—that is a human impossibility. The arm is bound to sway to and fro, even if ever so slightly, and the only way to hit the centre of the bull's-eye is to have the hammer fall just as the gun happens to be going across the mark.

Many persons believe, because a pistol kicks up when fired, that a marksman estimates how much the weapon is going to kick and aims at a correspondingly low point. The gun kicks, it is true, but that entails no guesswork on the part of the marksman. When the sights are fixed, allowance is made for the upward kick due to the recoil, and if the sighting of the shooter is accurate the shot will be accurate. With automatics, in which the recoil is utilized to expel the spent cartridge and insert a new one, it is not uncommonly believed that the shooter pulls the trigger and holds it back until all the shots are fired. If this were the case the weapon would kick up a little with every shot and the shooter would shoot himself in the face in the fraction of a second. These pistols shoot easily with a very slight trigger pull, but the trigger must be released and pulled for each shot.

MODERN DYNAMO ELECTRIC MACHINERY.*

BY

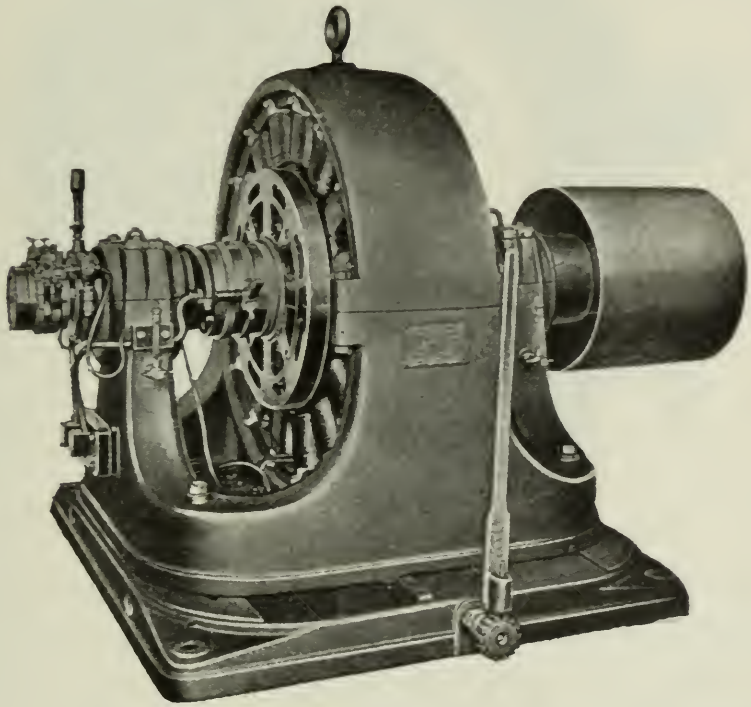
ALEXANDER GRAY, M.Sc.,

Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.

ALTERNATING-CURRENT GENERATORS.

We have already seen that direct-current machinery had become somewhat standardized by 1890, and that the Hobart machine, described on page 22, has design constants and a type of mechanical construction which do not differ much from those of similar machines of recent date, but at that time, 27 years ago, there was no one type of alternator that was considered superior to all others.

FIG. 32.



Belt-driven single-phase alternator, 90 k.w., 16,000 alternations.

The first Niagara machines, shown in Fig. 3, had an external rotating field system, this type of construction being considered necessary to give the large flywheel effect required to maintain the speed approximately constant with changing load. Rotating armature machines, such as that shown in Fig. 32, were still listed in 1903, and inductor alternators of the type shown in Fig. 33 were on the market as late as 1907, but the advantages of the present type of internal rotating field construction were such that by 1900 most of the other types had been discarded, so that Guilbert, in describing the alternators that had been on exhibit at the Paris Exposition in 1900, states as follows:

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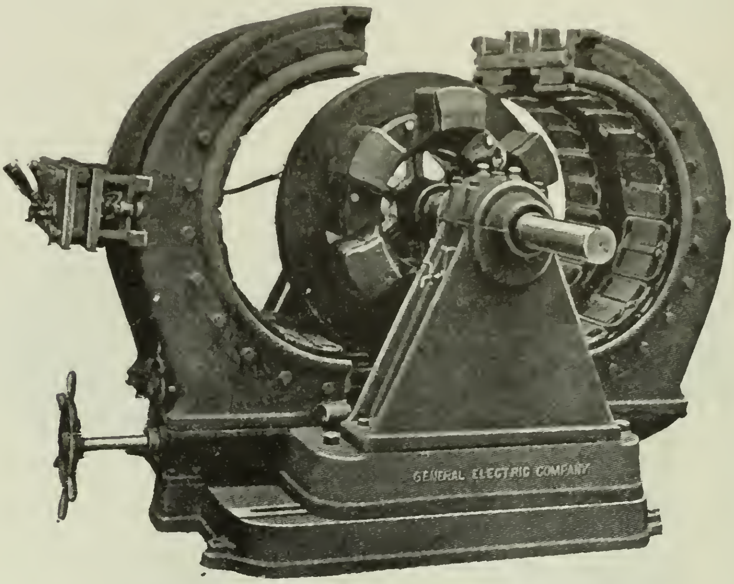
* Continued from page 48, July issue.

"One of the most striking features was the triumph of the three-phase system even for lighting; of equal interest was the fact, as had been foreseen before the opening of the Exposition, that the inductor type of alternator was being abandoned."

FIG. 33.



Inductor alternator with vertically split armature.

Many data have been published on these Paris machines.[14] From these data, and from some additional information published by Rothert,[15] the seven machines in Table III have been selected as typical alternators of 1900, and these we shall use as a starting point in our study of modern machines. Let us first, however, take up the various limitations in the design of polyphase alternators.

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[14] *L'Éclairge Électrique*, vol. 29, p. 276, November 23, 1901; *Electrical World*, vol. 37, pp. 113, 154, 194, 231, 274, 302, 352, 398, January to March, 1901.

[15] *L'Éclairage Électrique*, vol. 29, p. 307, November 30, 1901. See also "Engineering Evolution of Electrical Apparatus," Lamme, *Electric Journal*, vol. 11, p. 73.

TABLE III.

Kv.a	215	800	800	860	1000	1330	1400
Volts	220	2200	2200	2400	5000	5500	3000
Ampères	565	210	210	207	115	140	270
Phases	3	3	3	3	3	3	3
Frequency	32	42.5	50	50	50	25	50
R.p m.	120	80	79	94	94	75	72
Poles	32	64	76	64	64	40	84
Internal diameter of stator in inches	106	236	236	197	230	214	252
Frame length in inches	10	10	10.7	11	11.8	17	10
m. Pole pitch in inches	10.4	11.6	9.8	9.7	11.35	16.8	9.4
n. Air-gap clearance in inches	.197	.312	.275	.275	.312	.43	.235
Ratio m/n	52.5	37	35.5	35	36	39	40
Slots per pole	3	6	6	3	6	6	6
Size of slot in inches	1.85 dia.	.87 × 1.4	.6 × 1.15	1.7 × 2.5	1.1 dia.	1 × 2.7	.83 × 2.2
Conductors per slot	9	6	5	7	6	9	6
Connection	YYYY	delta	YY	Y	Y	Y	delta
Tooth/slot	—	1.24	1.72	.9	—	1.8	1.0
Maximum tooth density at no load in lines per square inch	104,000	110,000	65,000	115,000	104,000	77,000	100,000
Core density at no load	29,000	30,000	21,000	30,000	18,000	54,000	26,000
Pole density at no load	118,000	120,000	111,000	118,000	109,000	90,000	114,000
a. Ampère conductors per inch of periphery	365	375	320	450	370	450	570
b. Circular mils per ampère	740	430	450	620	725	1060	480
Ratio a/b	.49	.87	.71	.72	.51	.42	1.18
Peripheral velocity of rotor in feet per minute	3320	4950	4900	4850	5650	4200	4750
c. Ampère turns per pole at no load	5385	7600	4600	6950	5175	8050	6675
d. Armature ampère turns per pole	1920	2200	1600	2200	2100	3800	2750
Ratio c/d	2.8	3.45	2.87	3 15	2.46	2.12	2.42
Pole enclosure	.57	.5	.8	.61	.66	.65	.64
Output factor × 100	1.64	1.82	2.12	2.15	1.72	2.3	3 1

$$\text{Volts per phase} = 2.22 \times \text{conductors per ph.} \times \phi \times f \times 10^{-8}$$

$$\text{Tooth area per pole} = \text{minimum tooth} \times \text{slots per pole} \times \text{net iron in frame length.} \times \psi$$

$$\text{Pole density} = \text{gap flux} \times \text{leakage factor/pole area}$$

$$\text{Ampère conductors per inch of periphery} = \frac{\text{current per conductor} \times \text{conductors per phase} \times \text{phases}}{\pi \times \text{stator internal diameter}}$$

Ampère turns per pole at no load $= op$. Fig. 38.

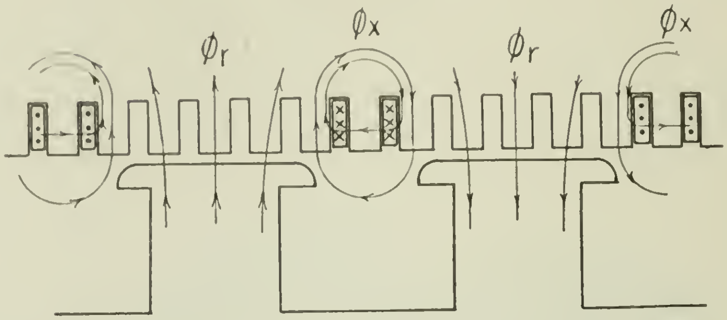
$$\text{Armature ampère turns per pole} = \frac{\text{current per conductor} \times \text{conductors per pole}}{2}$$

$$\text{Output factor} = \frac{\text{volt ampères}}{rpm \times D^2L}$$

PERFORMANCE CHARACTERISTICS.—Fig. 34 is a section of a three-phase alternator showing the conductors of only one phase. When this machine is supplying current, these conductors are encircled by the lines of force of the alternating magnetic fluxes

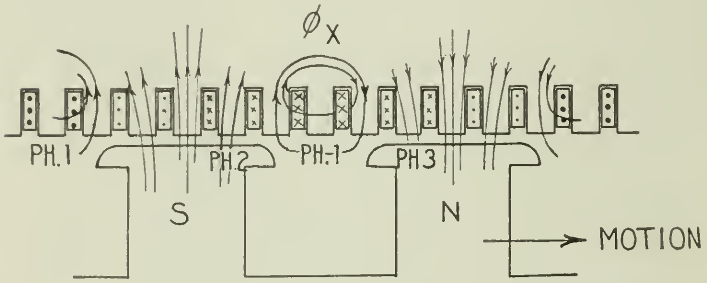
ϕ_x and ϕ_r. The former, often called the armature leakage flux, generates a voltage of self-induction in the conductors which is proportional to the current and is equal to IX where X, called the leakage reactance, is constant, since the flux ϕ_x is proportional to the current which produces it, the reluctance of the leakage path being practically all in the air part of the path. The magnetic flux ϕ_r enters the poles and so modifies the main field.

FIG. 34.



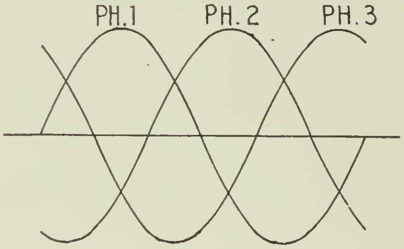
Armature fluxes produced by one phase of a three-phase alternator.

FIG. 35.



Armature field of a three-phase alternator when the current lags 90 degrees.

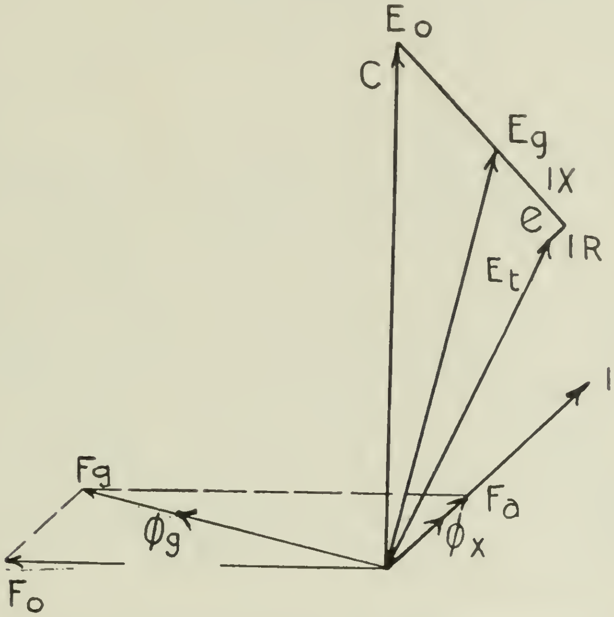
FIG. 35A.



Currents in three phases.

Fig. 35 shows a section through the same three-phase machine and shows the current distribution in the conductors when the power factor of the load is zero and the current lags 90 degrees behind the terminal voltage. Under these conditions the current is a maximum in the conductors that are between the poles, because in these conductors no electromotive force is being generated. The three fluxes ϕ_r, produced by the three phases, combine to give a gliding field exactly as in an induction motor, which field is proportional to the current flowing and moves at synchronous speed in the same direction as the rotating poles. The phase relation between this armature field and that produced by the poles depends on the power factor of the load and, as shown in Fig. 35, directly opposes the main field at zero power factor.

FIG. 36.



Vector diagram per phase of a polyphase alternator.

These effects of armature reaction can best be indicated by a vector diagram, as shown in Fig. 36.

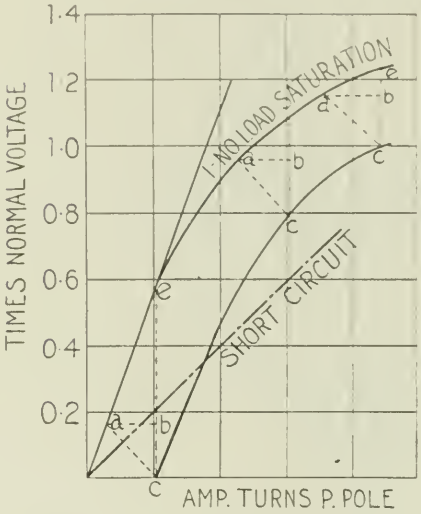
The no-load m.m.f. F_o produces an alternating flux in the winding of each phase, and the voltage E_o generated in each phase lags F_o by 90 degrees.

The m.m.f. of the armature produces a synchronous gliding field of constant magnitude and causes an alternating flux to thread the windings of each phase. It may be seen from Fig. 35 that the armature flux threading phase 1 is a maximum when the current in that phase has its maximum value; thus in Fig. 36 we have:

F_0 is the no load m.m.f.
E_0 is the voltage per phase due to F_0.
I is the current per phase.
F_a is the m.m.f. of armature reaction which, as pointed out in the last paragraph, is in phase with I.
F_g is the resultant m.m.f. due to field and armature.
ϕ_g is the resulting synchronous flux.
E_g is the voltage per phase due to ϕ_g.
ϕ_x is the armature leakage flux per phase.
IX is the leakage reactance drop.
E_t, the terminal voltage per phase, $= E_g - IX - IR$ taken as vectors.

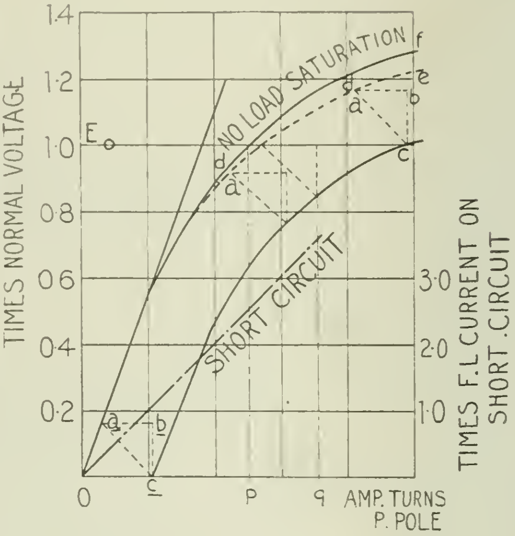
The voltage drop *ce* due to the combined effect of leakage reactance drop and drop due to armature reaction is generally called the synchronous reactance drop.

FIG. 37.



Characteristic curves of an alternator.

FIG. 38.



Test curves of a 150-kw., 600 r.p.m., three-phase alternator.

In the particular case when the power factor is zero and the current lags the terminal voltage by 90 degrees, the leakage reactance drop is subtracted directly from the generated voltage, and the magnetomotive force of armature reaction is subtracted directly from the exciting m.m.f. The voltage drop due to armature reaction, however, decreases as the poles become saturated, because the same m.m.f. produces a gradually decreasing reduction in the flux. These two effects are well shown in Fig. 37, where curve 1 is the no-load saturation, *ab* is the m.m.f. to overcome the demagnetizing effect of armature reaction, and *bc* is the voltage drop due to this effect, *bc* is the leakage reactance drop, and *c* is a point on the full-load saturation curve at zero power factor.

It is found in practice, however, that the two curves are not parallel to one another as shown, but gradually separate as in Fig. 38, which gives test data on an actual machine. The additional voltage drop is due to the pole leakage. The m.m.f. required to generate a voltage E_0 on no load is *op*, Fig. 38, but, when the alternator is loaded and the power factor is zero, the m.m.f. for the same generated voltage is *oq*; the flux crossing the air-gap is unchanged, but the leakage flux from pole to pole is increased in the ratio *oq*/*op*, and, under these conditions, an increased excitation is required because of the higher densities in the pole core. The relative amounts of these three effects can be shown as follows:

The distance *ab*, Fig. 38, is determined from the formula:

Demagnetizing ampère turns per pole = $0.35\ Z\ I_c/p$.

where Z/p is the total conductors per pole,

I_c is the current per conductor,

and the distance *bc* must be the leakage reactance drop; this can be checked approximately by calculation. If the triangle *abc* be now placed so that the full-load saturation curve found by actual test is the locus of the point *c*, then the locus of point *a* is what designers call the no-load saturation curve figured with the full-load leakage factor, and the excitation *ad* is the additional excitation for the poles over that required at no-load for the same air-gap flux.

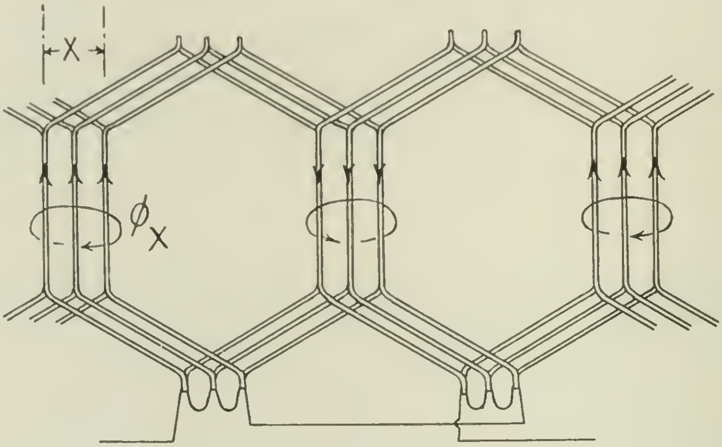
LIMITATIONS IN DESIGN.—If it is desired to have good regulation, particularly with low power factor loads, it is necessary to keep the synchronous reactance drop *fc*, Fig. 38, small compared with the normal voltage. To accomplish this result:

1. Keep the leakage factor small and the pole density below saturation.
2. Keep the leakage reactance small: this, as shown in Fig. 39, means limiting the number of ampère conductors in the phase belt x or, what is equivalent, limiting the number of ampère conductors per inch of armature periphery.
3. Keep the demagnetizing ampère turns per pole a small

fraction of the exciting ampère turns per pole and saturate the magnetic circuit so as to make the voltage drop *bc* small.

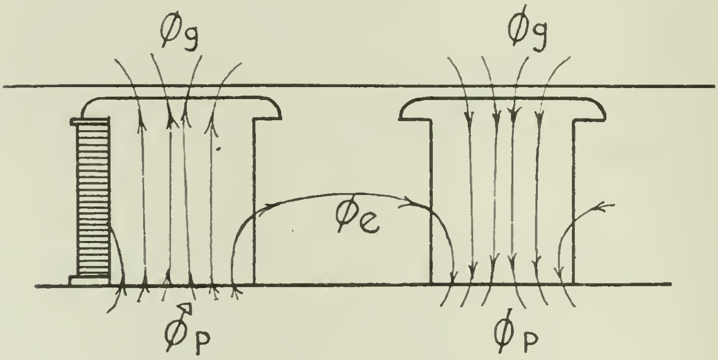
One may well ask why the output of this particular machine is limited to 150 kilowatts. Why would it not be possible to increase the main excitation and thereby allow a larger current to be carried by the armature without any sacrifice of regulation?

FIG. 39.



Winding of one phase of a three-phase alternator, showing the leakage flux.

FIG. 40.

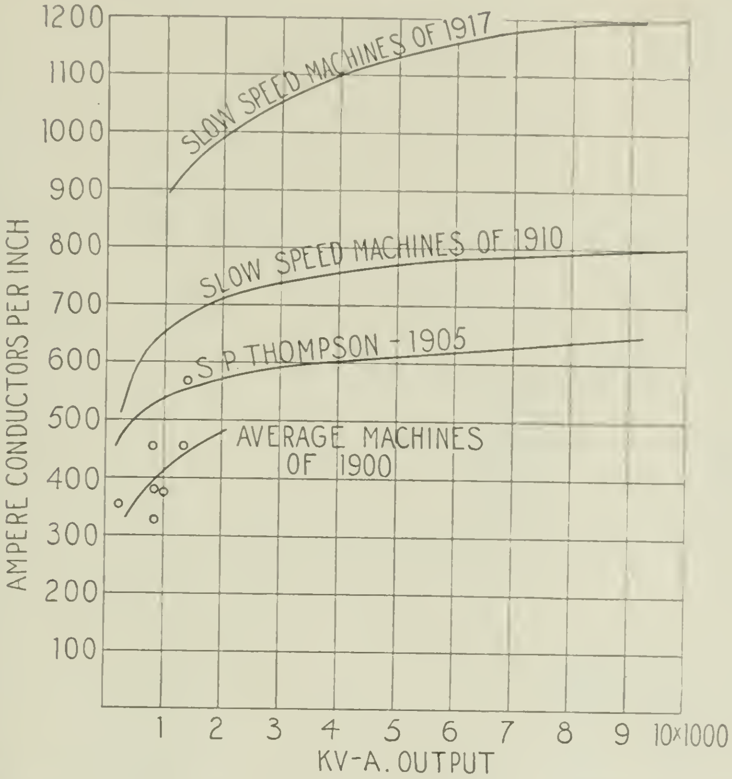


The main field and the pole leakage field of an alternator.

Fig. 40 shows part of a machine to scale. Of the flux ϕ_p which enters the pole, the leakage flux ϕ_l at no load is 20 per cent., and the useful gap flux ϕ_g is 80 per cent., under which conditions the pole density at the root is 100,000 lines per square inch, and the tooth density 95,000, while the length of the pole is just sufficient to give the necessary radiating surface to the field coils.

If, then, the field excitation is increased 50 per cent., the pole length will increase in the same ratio to dissipate the additional heat, the air-gap will be increased to use up the increased m.m.f., since ϕ_g, limited by the tooth density, remains constant, but the area as well as the m.m.f. of the leakage path will be increased, so that the leakage will become $(1.5)^2$, or 2.25 times the original value, and the flux density at the root of the pole will be excessive.

FIG. 41.



Values of ampère conductors per inch of periphery for slow-speed alternators.

For a satisfactory machine, therefore, all of the dimensions in Fig. 40 must increase as the ampère turns per pole are increased, so that one constant in design is the ratio ampère turns per pole/pole pitch, the value of which ratio can be increased either by raising the permissible temperature rise of the field coils or by improving the ventilation. It is of interest to note, however, that, in order to obtain a certain desired voltage regulation, the armature ampère turns per pole are made a definite fraction of the main excitation, so that the constant used by the designer is rather the ratio of armature ampère turns per pole/

pole pitch, of which the ampère conductors per inch of armature periphery are a definite measure. This constant, therefore, which we found to be of great importance in direct-current design, is of equal importance in the design of alternators, but, since its value depends on so many factors, the writer who gives a table of values is subject to criticism. Let us, however, examine a few machines and see what values are found in practice.

TABLE IV.

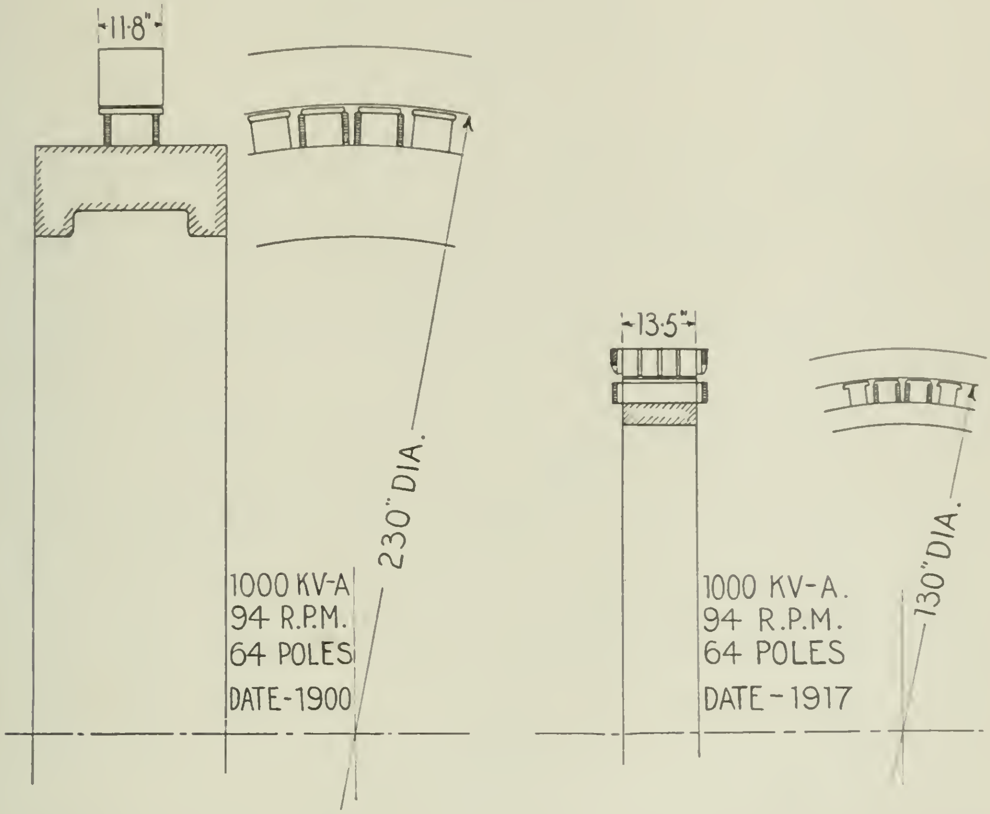
Kv.a.	1000
Phases	3
Frequency	50
R.p.m.	94
Poles	64

Date	1900	1917
Internal diameter of stator in inches	230	130
Frame length in inches	11.8	13.5
Centre vent ducts	None	3 of ½ inch
End vent ducts	None	2 of 1 inch
m. Pole pitch in inches	11.35	6.4
n. Air-gap clearance in inches	5/16	3/16
Ratio *m/n*	36	34
Slots per pole	6	6
Size of slot in inches	1.1 dia.	.5×2.75
Tooth slot	0.8	1.12
Maximum tooth density at no load in lines per sq. in.	104,000	100,000
Core density,	18,000	50,000
Pole density	109,000	95,000
a. Ampère conductors per inch	370	900
b. Circular mils per ampère	725	750
Ratio *a/b*	.51	1.2
Peripheral velocity of rotor in feet per minute	5700	3200
c. Ampère turns per pole at no load	4500 by test	3700
d. Armature ampère turns per pole	2100	2880
Ratio *c/d*	2.15	1.28
Pole enclosure	0.66	0.7
Output factor	0.0172	0.047
Guaranteed temperature rise	40° C.	50° C.

Table III gives data on several of the machines that were exhibited at the Paris Exposition; the 1400-kv.a. machine is of special interest because Rothert claims that it is so much superior to other machines of that time. The values of ampère conductors per inch found in these machines are plotted in Fig. 41, and on the same diagram are plotted figures given by S. P.

Thompson in 1905; these indicate the improvement in ventilation in five years. The figures of 1910 are higher because operating engineers were willing to accept poorer regulation in order to get a cheaper machine, while the enormous increase in the last seven years is due partly to the fact that the larger machines are now rated at 50° C. rise with no overload guarantee, but more particularly to the fact that regulation has been thrown to the winds and the voltage maintained at all loads and power factors by voltage regulators such as these first invented by Tirrell.

Fig. 42.



Comparison between a machine built in 1900 and one built in 1917 for the same output.

Perhaps the best conception of the progress made in design, and of the entire change in performance characteristics, may be obtained from Table IV, which gives comparative data on the 1000-kilovolt-ampère machine exhibited at the Paris Exposition and on a unit as designed to-day for the same output. The two machines are drawn to scale in Fig. 42, and the performance characteristics are given in Fig. 43. With an excitation necessary to give normal voltage on no-load, the current on short-circuit is 2.75 times full-load current in the early machine and is only 1.5 times full-load current in the more recent design. In the case of alternators of large output, when the air-gap clearance is not limited partly by mechanical clearance, the short-circuit current with normal no-load excitation does not greatly exceed the full-load value.

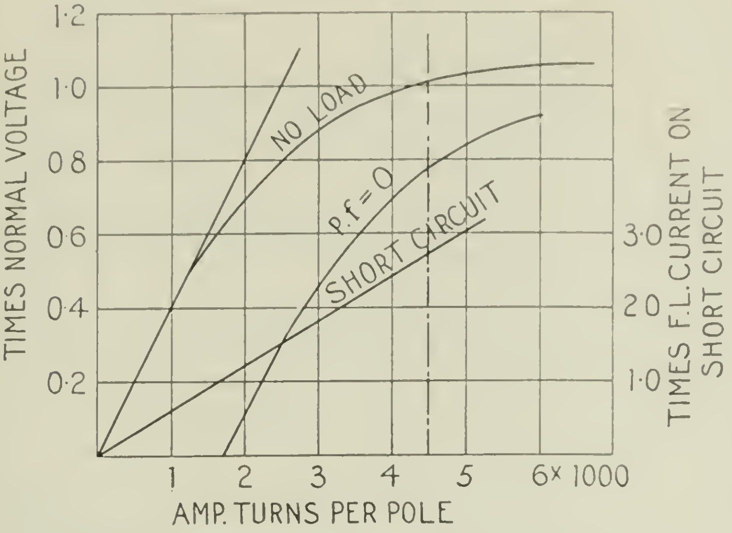
The regulation guarantees expected at various times have been:

Date	Regulation at 100 per cent. power factor Per cent.	Regulation at 80 per cent. power factor Per cent.
1900	5	15
1910	8	20
1917	20	40

The method of obtaining good regulation in the early machines was, as shown in Fig. 43*a*, to saturate the magnetic circuit and to use a small number of ampère conductors per inch of periphery. Since it was not possible to use high tooth densities as in direct-current machines because of the high frequency and the stationary armature, it was usual to run the pole density above saturation, and this often caused an excessive drop in voltage, due to pole leakage. The machines, therefore, would not give an overvoltage if this was desired; the iron going into the machine had to be carefully tested for permeability and the leakage fluxes and saturation curve closely calculated; the machines also were large for their output. The tendency in America until almost 1900 was to build a cheaper machine, of poorer inherent regulation, and to compound or compensate the machine for voltage drop; series excitation was obtained by some kind of rectifying device such as that shown on the end of the shaft in Fig. 32. This scheme worked well on the small single-phase units used for lighting service, because the power factor was approximately constant, but it gradually lost favor as the polyphase system came into general use.

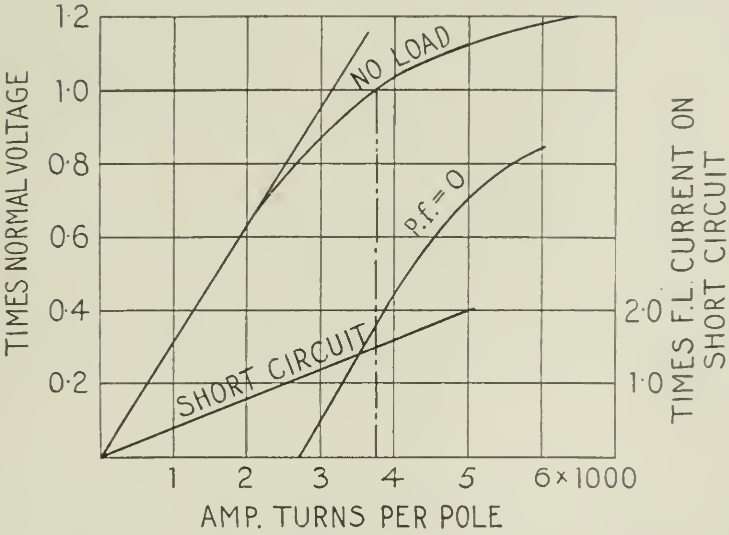
The extent to which alternators have been gradually rated up is well indicated by the curves of output constant given in Fig. 44. It is of interest to note from these curves that, contrary to general opinion, the core dimensions of an alternator are greater than those of a direct-current machine of the same output. This is due principally to the fact that, whereas in direct-current machines tooth densities of 150,000 lines per square inch are not exceptional, values of 100,000 lines per square inch cannot safely be exceeded in 60-cycle alternators, because the loss at that frequency is large, while the ventilation of a stationary core is not nearly so effective as is that of a rotating armature.

FIG. 43A



Performance characteristics of the machine built in 1900.

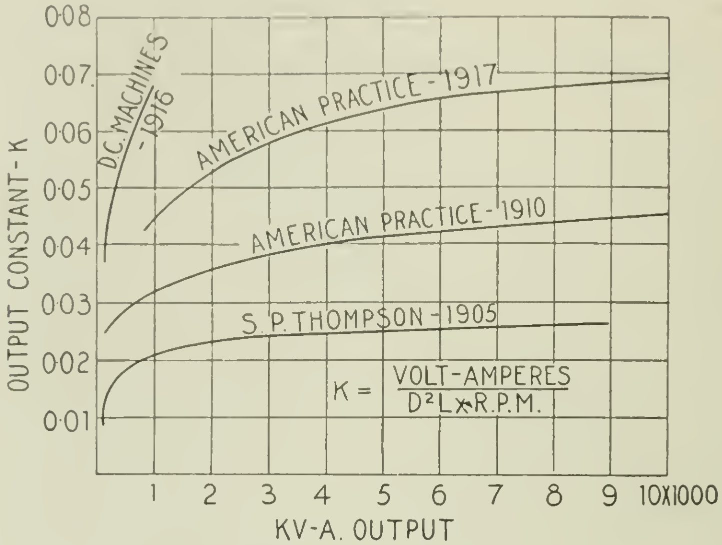
FIG. 43B.



Performance characteristics of the machine built in 1917.

VENTILATION.—Many of the early alternators were so large for their output that no special provision was necessary in order to keep the temperature rise down to a safe value. The machine shown in Fig. 42, for example, does not even have vent ducts in the stator. Even in the case of modern machines, the slow-speed alternator does not require that any special precautions be taken to keep it cool, and it is only as the speed for a given output increases, and therefore the dimensions decrease, that the problem becomes difficult.

FIG. 44.



Output constants of slow-speed alternators.

The temperature rise is proportional to $\frac{\text{watts loss}}{\pi DL(a + bV)}$ where

πDL is the armature surface
V is the peripheral velocity of the armature
a and b are radiation and convection constants respectively.

$$\text{The output in } Kv.\ a. = \frac{D^2L \times rpm}{K} = (DLV) \times \text{a constant},$$

$$\text{therefore temperature rise} = \frac{\text{watts loss}}{(a + bV)} \times \frac{V}{\text{output}} \times \text{a constant}$$

$$= (\text{per cent. loss}) \times \left(\frac{V}{a + bV}\right)$$

so that, for a given output and a given efficiency, the higher the peripheral velocity the more difficult it is to keep the machine cool. But note further that

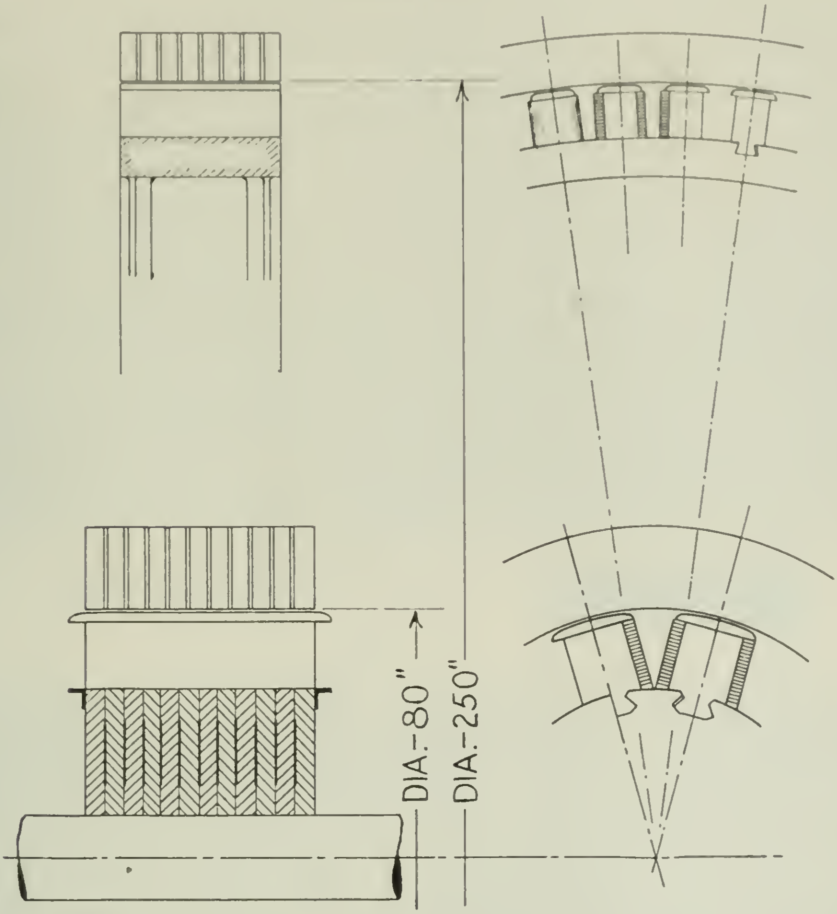
$$V = \frac{\pi D}{12} \times \text{rpm}$$

$$= \frac{\pi D}{12} \times \frac{120 f}{p}$$

$$= 10 \times \text{pole pitch} \times \text{frequency}$$

so that, for a given output and given frequency, the greater the pole pitch the more difficult it becomes to keep the machine cool. This is shown in rather a striking way if we compare two water-wheel generators, one to operate on a high head and the other on a low head: compare, for example,

FIG. 45.



Comparison between two 10,000-kv.a. water-wheel generators, one of 100 r.p.m. and the other of 600 r.p.m.

Kv.a.	10,000	10,000
Rpm.	600	100
Poles	12	72

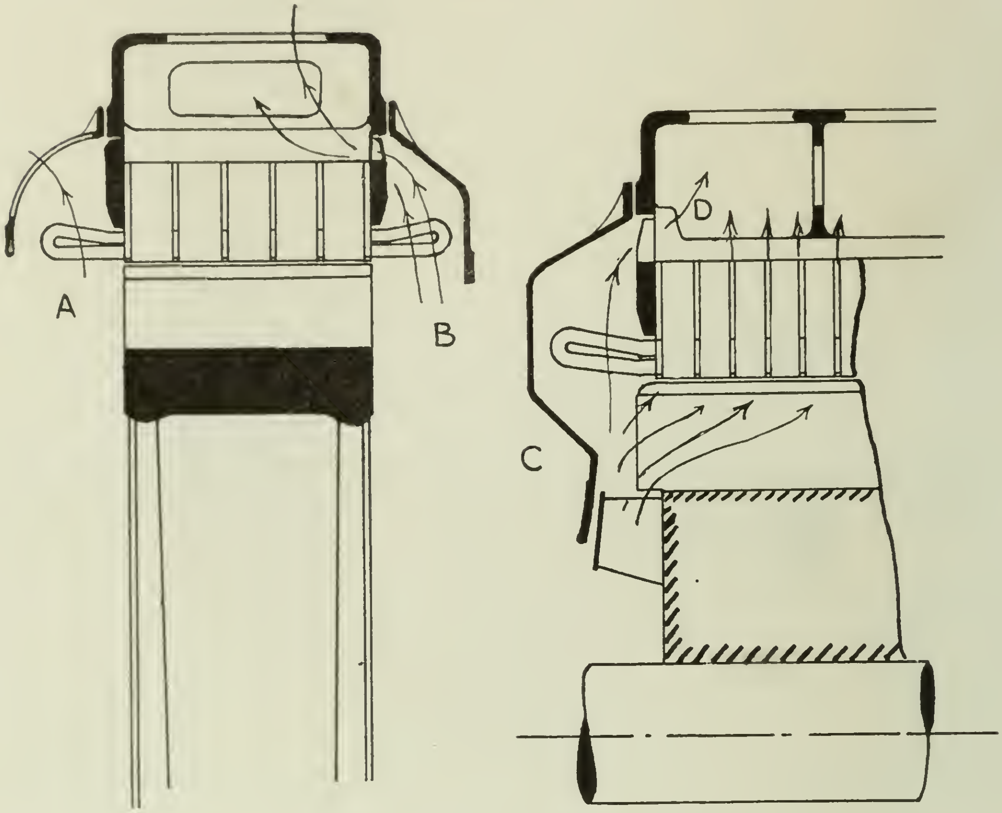
Probable dimensions are:

Internal diameter of stator in inches	80	250
Frame length in inches	37	26
Pole pitch in inches	21	10.9
Peripheral velocity of rotor in feet per minute	12,500	6500
Peripheral velocity at run-away speed	22,500	11,700

These machines are drawn to scale in Fig. 45, and it can now be readily seen why the high-speed machine is so difficult to ventilate: it has not the radiating surface of the slow-speed machine.

In slow-speed machines the air is stirred up around the stator by the rotor itself, no fan blades being necessary. The whole construction is open, as shown in Fig. 47, and also in diagram A, Fig. 46. With this type of ventilation the air is not always directed where desired, and the air streams are rather unstable, so that one side of the machine is often cooled better than is the other. With moderate-speed machines it becomes necessary to properly direct the air, which result is generally accomplished by the addition of fans to the rotor, while the housings are often made solid, as shown in Fig. 48, and also in diagram B, Fig. 46, so as to deflect the air over the back of the stator windings and core.

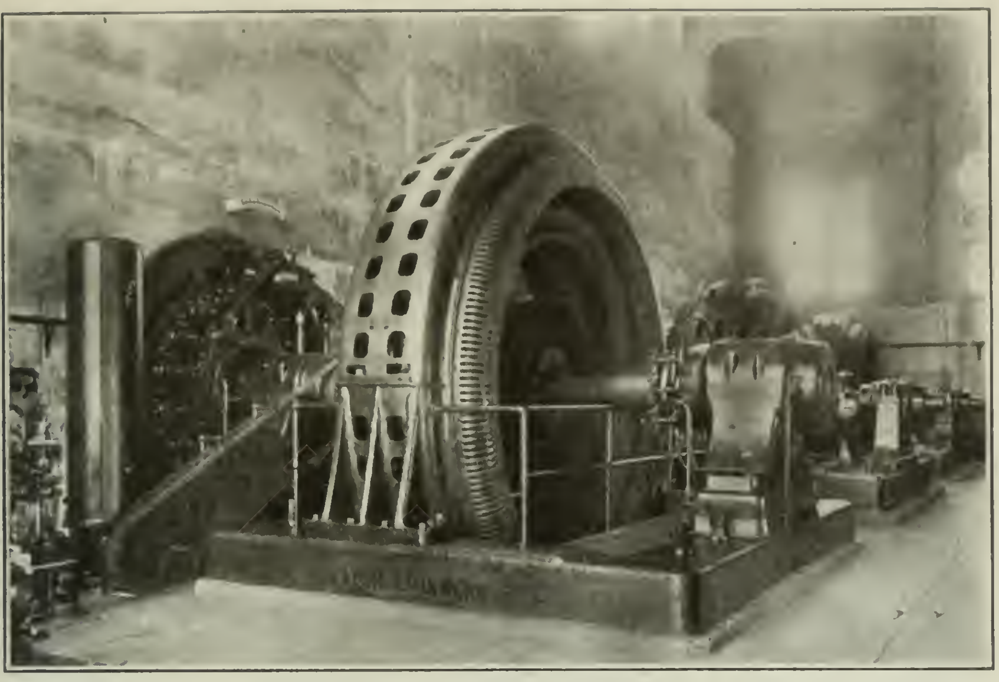
FIG. 46.



Different methods of ventilating alternators.

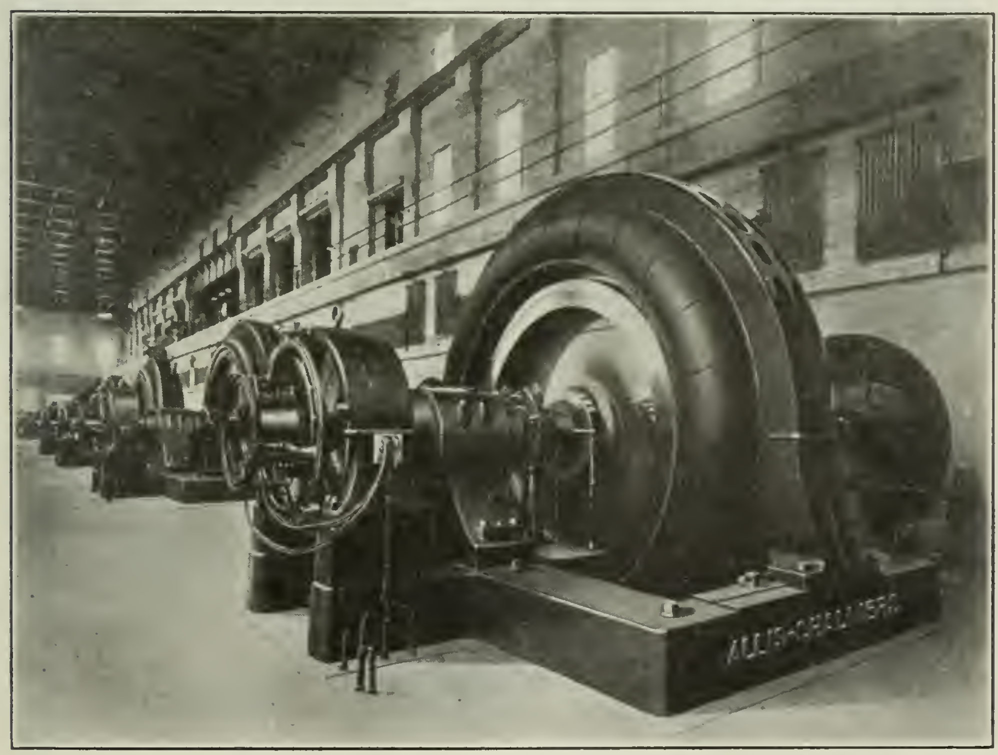
In the case of high-speed water-wheel units, under which

FIG. 47.



Generator with open end bells.

FIG. 48.

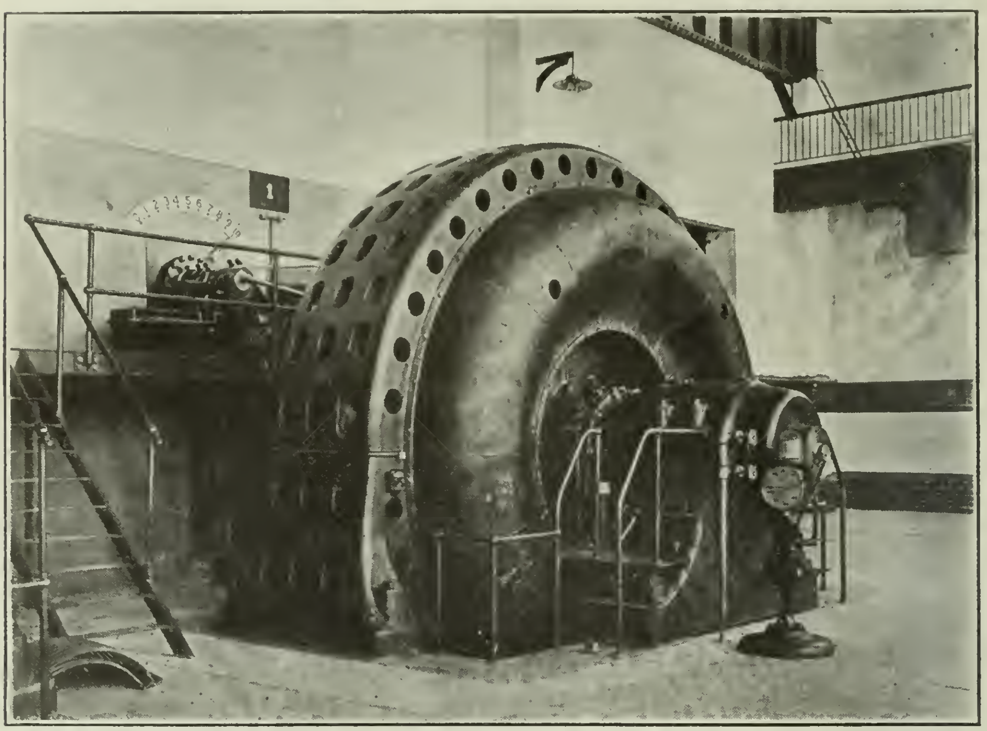


Generator with solid end bells.

class would come the 600-r.p.m. machine in Fig. 45, the frame is generally long in order to keep the peripheral velocity down to a safe value, and in such cases it is necessary to create an air-pressure in the end bells to force the air between the poles and out through the vent ducts in the centre of the stator core, as shown in diagram C, Fig. 46, and also in Fig. 49; comparatively small openings are left at *D*, Fig. 46, to ventilate the end bells.

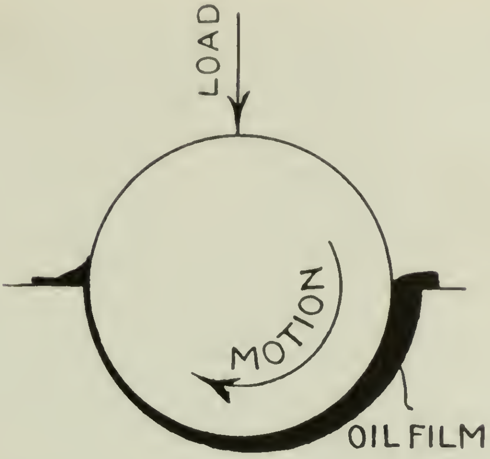
MECHANICAL CONSTRUCTION.—One feature of interest is the growing popularity of the vertical shaft or umbrella type of water-wheel generator. This has been due partly to improvements in the design of this type of water-wheel, but also in large measure to the development of a reliable thrust bearing. The Kingsbury bearing makes use of that feature of the horizontal shaft bearing on which its ability to carry large pressures depends; namely, that, as shown in Fig. 50, the oil is drawn into the high-pressure space as a wedge, by the rotation of the shaft itself. The stationary thrust plate of this type of bearing is made of a number of segments, as shown in Fig. 52, these seg-

FIG. 49.



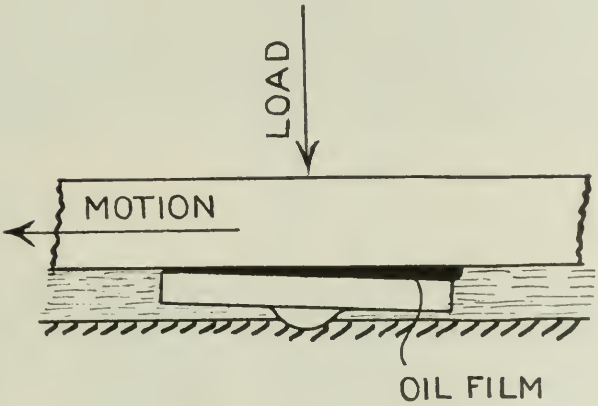
Generator with enclosing end bells and forced ventilation.

FIG. 50.



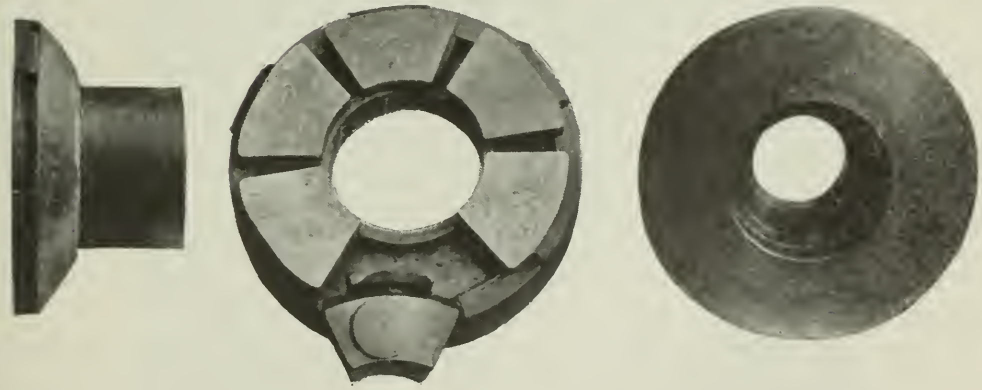
Oil film in the bearing of a horizontal shaft.

FIG. 51.



Oil film in the Kingsbury thrust bearing.

FIG. 52.

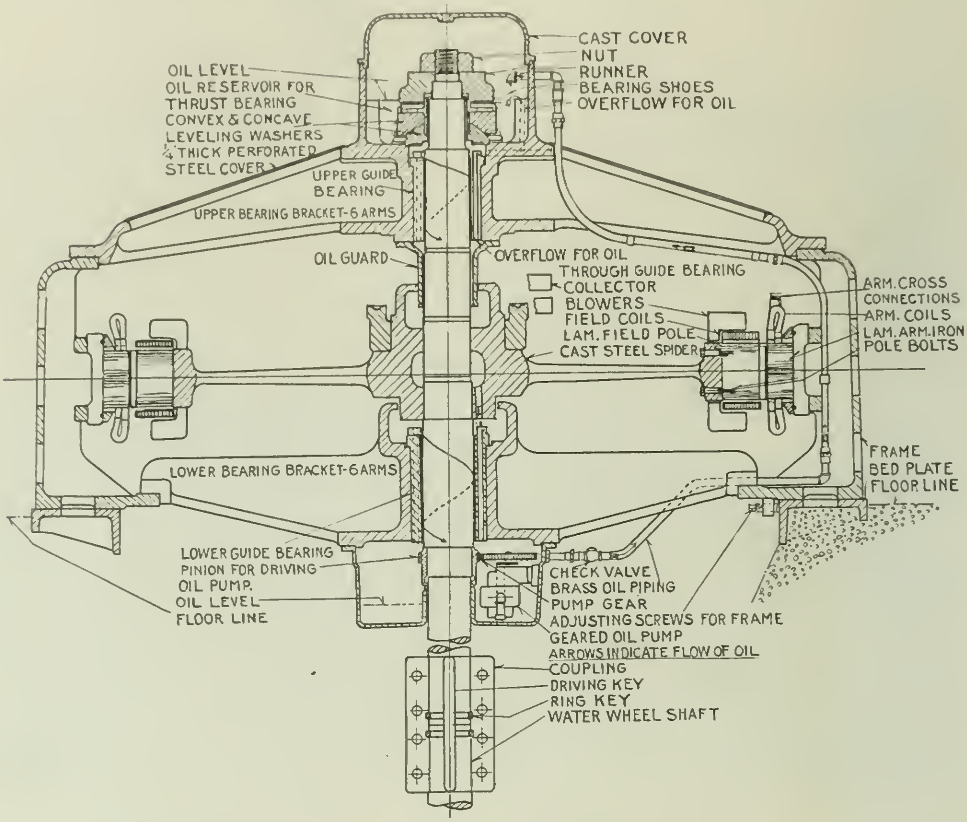


Parts of a Kingsbury thrust bearing.

ments being free to tilt, so that when the upper plate rotates in the direction shown in Fig. 51, the lower plates tilt and the oil wedge is formed as indicated. Such a bearing will carry an average load of 350 pounds per square inch, which is about seven times the safe value for an ordinary thrust bearing.

Fig. 53 shows the arrangement of the guide and thrust bearings of such a vertical generator, Fig. 54 shows the very substantial support used to carry the weight, and Fig. 55 shows one method adopted to force the air into the centre of the long core of these machines. The core length of water-wheel generators of large output is generally longer than it would be for engine-driven units, because the diameter has to be kept small so that the stresses due to centrifugal force will not be excessive should the generator run away, due to faulty operation of the governing mechanism of the water-wheel.

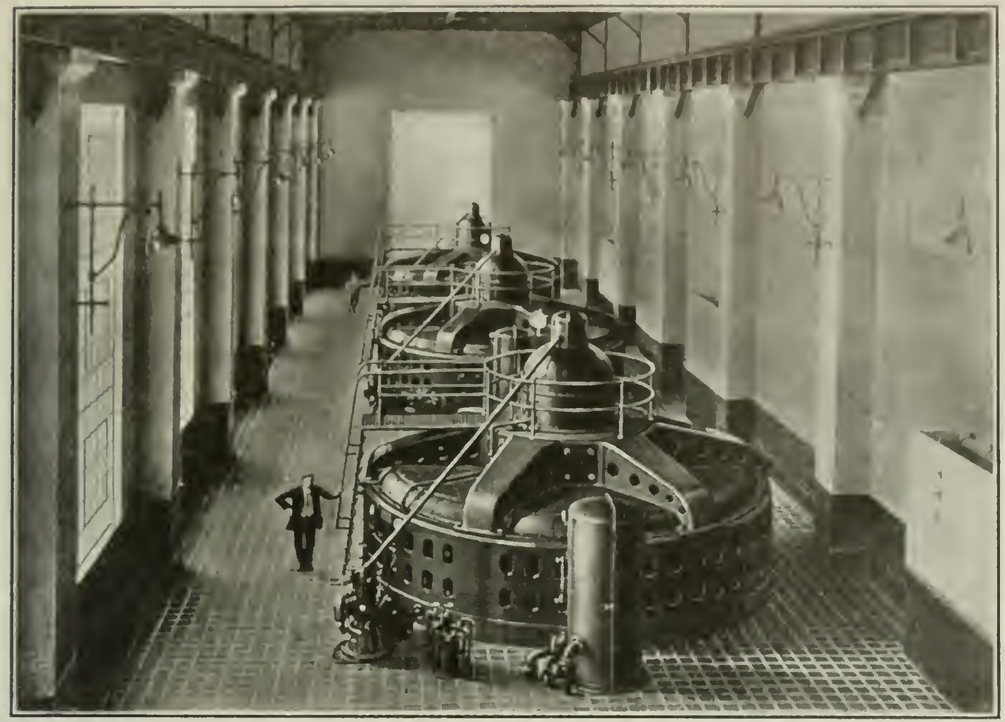
FIG. 53.



Section of Westinghouse generator with two guide bearings.

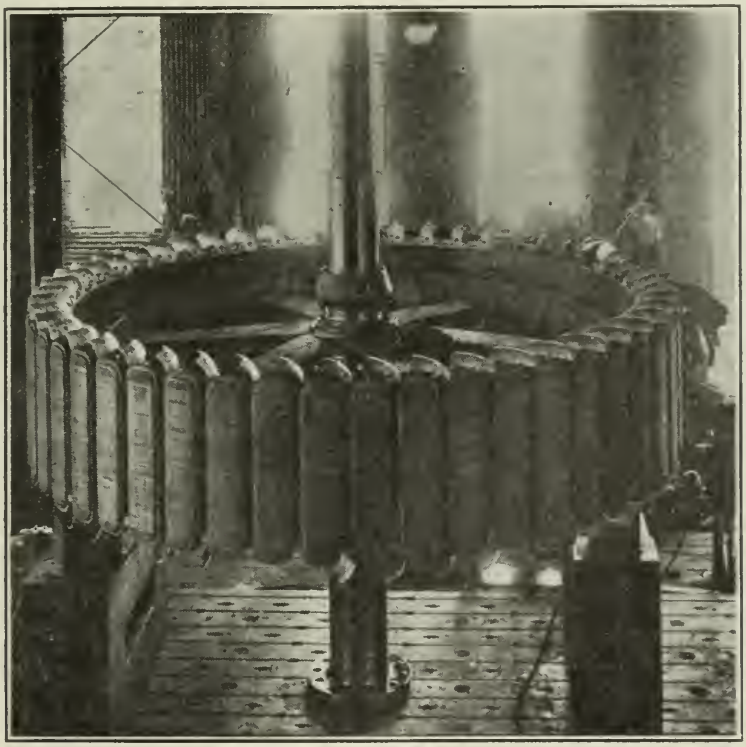
It is generally assumed that the cost and weight of a machine for a given kilowatt output go down as the speed is increased.

FIG. 54.



Three 7800-kv.a., 144-r.p.m. vertical generators with Kingsbury thrust bearings.

FIG. 55.



Rotor for a 10,000-kv.a., 144-r.p.m. vertical generator.

It is true that the value of D^2L decreases, but when the speed reaches such a value that a radical change in the type of construction becomes necessary, as for example when one has to change from the simple cast-steel spider with bolted-on poles to the expensive construction shown in Fig. 45, where the rotor is built up of steel plates, then the labor cost becomes a larger proportion of the total cost, and the factory cost of the machine will not always be reduced.[16]

(*To be continued.*)

America's Longest Railway Tunnel. ANON. (*The Contract Record,* vol. 31, No. 21, p. 449, May 23, 1917.)—The Rogers Pass Tunnel, officially known as the Connaught Tunnel, on the line of the Canadian Pacific Railway through Selkirk Range of the Rocky Mountains in British Columbia, was placed in service on December 9, 1916. The completion of the Connaught Tunnel is without doubt the most notable achievement in the art of tunnelling ever accomplished on the American continent. To complete a rock tunnel, five miles long, in practically three years, under conditions by no means easy, is an undertaking that might well be termed a brilliant success. The growing traffic congestion of this division of the Canadian Pacific Railway lines made the greatest speed construction essential. To meet the urgency demanded by the railway, methods somewhat removed from the conventional were obviously a necessity.

The rapidity of headway was a result of the combination of two elements—a new mode of heading attack and a revised plan of enlargement. In both of these distinct progress is evident upon the practices heretofore accepted. First, a pioneer bore, inaugurated as an experiment, was looked upon with distrust by many authoritative tunnelling engineers, because it did not follow the precedent set by prior rock tunnelling. The enlargement operations further demonstrated the success of progressive ideas. The adoption of a central heading of such size as to permit radial drilling for the final enlargement proved its value, as the speed of driving, averaging 16 to 20 feet daily, constituted a record. Blasting in rings on planes perpendicular to the tunnel axis, although an innovation, contributed to phenomenal progress. Engineers throughout the world have expectantly watched the progress of this experiment. The experiment has been successful, stereotyped processes are at least doomed to revision, and the achievement at Rogers Pass will be an incentive for still further progress in this important branch of engineering.

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[16] Behrend. *Electrical Review,* New York, vol. 45, September 10, 1904 (p. 375).

THE PHYSICAL BASIS OF COLOR-TECHNOLOGY.*

BY

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One of the most annoying features of dyes is the extreme rarity of pure blue dyes. Nearly all blue dyes, Table VII, transmit the extreme red rays quite freely, and the scarcity of blue-green dyes which are not dichroic makes it difficult often to find a combination which transmits only the violet rays. In extremely high concentrations or great depths some blue dyes effectually absorb most of the extreme red rays.

In Table VIII are presented a number of spectral analyses grouped under the common name of purple for the purpose of classification. An interesting case is that of ethyl violet in gelatine, both wet and dry. After the dyed gelatine, which was flowed on clear glass, had set, and while still wet, the spectral analysis was made. The sample was then allowed to dry and another spectral analysis was made. On plotting these data a decided difference in the spectral transmission curves is seen, as indicated by the numerical data. The wet specimen is decidedly more reddish than when dry, and an actual shift in the absorption band takes place on drying. Although not definitely established, this may be explained as due to a difference in the refractive index of the solvent in the two cases. The data are corrected for reflections from the gelatine and glass surfaces.

In Table IX are presented spectral analyses of dyed gelatine filters before and after fading by exposure to solar radiation. Such data are of special interest in many cases, and it appears of interest to make a thorough study of the fading of dyes with the aid of spectral analyses. Certainly no great amount of information is available regarding the relation of the spectral character of radiation to the spectral deterioration of dyes or the relation of either of these to the chemical composition. Some work along this line is in progress. Incidentally, the testing of dyes under illuminants containing ultraviolet rays of extremely short wavelengths which are practically absent in solar radiation at the

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* Concluded from page 93, July issue.

TABLE IV.

Spectral Transmission Factors of Red Dyes.

	0.44μ	0.46μ	0.48μ	0.50μ	0.52μ	0.54μ	0.56μ	0.58μ	0.60μ	0.62μ	0.64μ	0.66μ	0.68μ	0.70μ
Carmen ruby opt.	....	....	....	....	....	....	....	....	....	0.04	0.18	0.37	0.49	0.60
Amido naphthol red	....	....	....	....	....	....	....	....	0.04	.38	.75	.92	.96	.96
Coccinine	....	....	....	....	....	....	....	0.04	.56	.96	.98	.98	.98	.98
Erythrosine	0.06	....	....	....	....	....	0. 1	.53	.90	.95	.96	.96	.96	.96
Hematoxyline	.01	0.03	0.07	0.13	0.14	0.12	.13	.25	.44	.54	.63	.73	.78	.82
Hematoxyline	....	....	....	....	....	....	....	.01	.02	.04	.09	.15	.21	.25
Alizarine red	.01	.01	.02	.03	.04	.06	.11	.22	.39	.54	.65	.72	.77	.79
Acid rosolic (pure)	.04	.03	.01	....	....	....	.02	.38	.78	.88	.90	.91	.92	.92
Rapid filter red	....	....	....	....	....	.01	.10	.47	.86	.95	.96	.96	.96	.96
Aniline red fast extra A	....	....	....	....	....	.02	.12	.34	.55	.72	.84	.88	.90	.92
Pinatype red fast	....	....	....	....	....	....	....	....	.11	.35	.55	.65	.68	.69
Eosine (yellowish)	....	....	....	....	....	....	....	....	.06	.40	.63	.74	.82	.85
Eosine	....	....	....	....	....	....	.01	.54	.87	.93	.92	.92	.92	.92
Naphthalinrot in absolute alcohol	....	....	....	....	....	....	....	....	.06	.28	.43	.50	.57	.61
Rose bengal	.80	.70	.34	.06	.01	....	.14	.82	.96	.97	.98	.98	.98	.98
Rose bengal	.01	....	....	....	....	....	....	.09	.57	.83	.89	.92	.94	.96
Cobalt ammonium sulphate	.60	.56	.48	.37	.38	.53	.70	.82	.86	.90	.90	.90	.90	.89
Cobalt nitrate	.69	.51	.40	.31	.32	.48	.67	.82	.87	.90	.90	.90	.90	.90

TABLE V.

Spectral Transmission Factors of Yellow Dyes.

	0.44μ	0.46μ	0.48μ	0.50μ	0.52μ	0.54μ	0.56μ	0.58μ	0.60μ	0.62μ	0.64μ	0.66μ	0.68μ	0.70μ
Tartrazine.	. . . .	. . . .	. . . .	. . . .	0.07	0.52	0.75	0.86	0.91	0.95	0.96	0.97	0.98	0.98
Chrysoidin.	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	.02	.23	.50	.71	.79	.79
Aurantia.	. . . .	. . . .	. . . .	. . . .	. . . .	.03	.23	.53	.82	.92	.96	.96	.96	.96
Aniline yellow phosphine.	. . . .	. . . .	. . . .	. . . .	.02	.20	.43	.60	.67	.75	.81	.85	.86	.87
Fluorescein.	0.15	0.01	. . . .	. . . .	.48	.91	.97	.98	.98	.98	.98	.98	.98	.98
Aniline yellow fast S.	. . . .	. . . .	0.01	0.07	.43	.84	.96	.96	.96	.96	.96	.96	.96	.96
Methyl orange indicator.	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	.01	.31	.70	.79	.80	.81	.81	.81
Auramin.	. . . .	. . . .	.01	.39	.77	.83	.84	.86	.87	.88	.90	.92	.93	.93
Uranine.	.15	.01	. . . .	.01	.58	.96	.97	.97	.97	.97	.97	.97	.97	.97
Uranine naphthaline.	. . . .	. . . .	. . . .	.04	.53	.77	.82	.83	.84	.85	.86	.86	.87	.87
Orange B naphthol.	. . . .	. . . .	. . . .	. . . .	. . . .	.01	.43	.88	.95	.96	.97	.97	.97	.97
Safranine.	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	.03	.27	.64	.85	.93	.93
Martius gelb.	. . . .	. . . .	. . . .	.01	.43	.84	.91	.94	.95	.95	.95	.95	.95	.95
Naphthol yellow.	. . . .	. . . .	.01	.18	.74	.91	.96	.97	.98	.98	.98	.98	.98	.98
Potassium bichromate, sat. sol.	. . . .	. . . .	. . . .	. . . .	. . . .	.10	.60	.84	.88	.89	.89	.89	.89	.88
Cobalt chromate.	.17	.36	.62	.82	.88	.90	.92	.93	.95	.96	.96	.96	.96	.95

TABLE VI.

Spectral Transmission Factors of Green Dyes.

	0.44μ	0.46μ	0.48μ	0.50μ	0.52μ	0.54μ	0.56μ	0.58μ	0.60μ	0.62μ	0.64μ	0.66μ	0.68μ	0.70μ
Naphthol green	0.02	0.04	0.07	0.21	0.30	0.36	0.29	0.16	0.07	0.02	0.01	....	....	....
Brilliant green	.04	.39	69	.52	.23	.04	....	....	....	....	....	0.02	0.23	0.64
Filter blue-green	.35	.49	.64	.70	.60	.37	.13	.02	....	....	....	....	....	....
Filter blue-green	.06	.14	.23	.40	.26	.08	.01	....	....	....	....	....	....	....
Malachite green	....	.12	.20	.08	.01	....	....	....	....	....	....	....	.12	.50
Malachite green	....	.01	.04	.01	....	....	....	....	....	....	....	....	.02	.23
Malachite green	....	....	.01	....	....	....	....	....	....	....	....	....	....	.10
Saurgrün	.03	.29	.57	.57	.39	.19	.04	.01	....	....	....	....	.04	.30
Methylengrün	.28	.31	.32	.26	.17	.07	.02	01	....	....	....	....	.03	.28
Methylengrün	.14	.16	.17	.13	.06	.01	....	....	....	....	....	....	.02	.14
Aniline green naphthol B	.02	.06	.14	.24	.34	.40	.32	.14	.04	.01	....	....	....	....
Aniline green naphthol B	....	....	.02	.06	.10	.15	.09	.02	....	....	....	....	....	....
Neptune green	....	.40	.63	.41	.13	.01	....	....	....	....	....	....	....	.05
Neptune green	....	.19	.36	.18	.02	....	....	....	....	....	....	....	....	.02
Cupric chloride	.77	.84	.89	.92	.92	.89	.80	.67	.52	.36	.19	.06	.02	....

TABLE VII.

Spectral Transmission Factors of Blue Dyes.

	0.44μ	0.46μ	0.48μ	0.50μ	0.52μ	0.54μ	0.56μ	0.58μ	0.60μ	0.62μ	0.64μ	0.66μ	0.68μ	0.70μ
Turnbull's blue	0.58	0.60	0.56	0.51	0.38	0.28	0.18	0.09	0.05	0.03	0.01	....	....	....
Victoria blau	.52	.23	.09	.01	....	....	....	....	....	.01	.04	0.21	0.49	0.73
Prussian blue (soluble)	.66	.71	.76	.69	.60	.46	.32	.20	.12	.07	.05	.03	.03	....
Prussian blue (soluble)	.06	.09	.09	.05	.02	.01	....	....	....	....	....	....	....	....
Wässer blau	.89	.75	.51	.26	.07	.01	....	....	.01	.02	.06	.18	.37	.60
Wässer blau	.85	.66	.42	.17	.03	.01	....	....	....	.01	.03	.10	.26	.48
Resorcine blue	.25	.18	.06	.02	.01	....	....	....	.01	.02	.14	.41	.64	.72
Toluidin blau	.66	.31	.13	.03	.01	....	....	....	....	....	.01	.04	.16	.40
Patent blue	.83	.91	.84	.76	.65	.46	.24	.08	.02	....	....	.06	.42	.78
Patent blue	.15	.25	.17	.05	....	....	....	....	....	....	....	....	....	.12
Dianil blue	.77	.69	.59	.48	.35	.24	.15	.09	.05	.05	.07	.14	.29	.53
Dianil blue	.38	.30	.18	.10	.04	.01	....	....	....	....	....	....	.02	.12
Filter blue	.84	.79	.66	.44	.27	.17	.14	.19	.36	.56	.74	.81	.88	.92
Filter blue	.35	.29	.18	.05	....	....	....	....	.02	.08	.23	.44	.62	.71
Aniline blue, methyl	.92	.88	.78	.52	.27	.09	.03	.02	.02	.04	.08	.16	.25	.45
Aniline blue, methyl	.44	.31	.13	....	....	....	....	....	....	....	....	....	....	....

TABLE VIII.

Spectral Transmission Factors of Purple Dyes.

	0.44μ	0.46μ	0.48μ	0.50μ	0.52μ	0.54μ	0.56μ	0.58μ	0.60μ	0.62μ	0.64μ	0.66μ	0.68μ	0.70μ
Ethyl violet in gelatine (dry)	.97	.87	.67	.28	.04	....	....	....	....	.05	.33	.73	.88	.91
Ethyl violet in gelatine (wet)	.83	.79	.45	.07	.01	....	0.01	0.03	0.05	.15	.42	.76	.91	.93
Magenta	.21	.08	02	.01	....	....	.01	.22	.73	.93	97	.97	.97	.97
Magenta	....	....	....	....	....	....	....	....	.07	.48	.81	.92	.95	.95
Gentiana violet	.89	.83	.64	.44	.26	.19	.15	.10	.13	.42	.75	.92	.93	.94
Gentiana violet	.11	.01	....	....	....	....	....	....	....	....	.01	.15	.48	.66
Rosazeine	.50	.28	.02	....	....	....	....	.06	.55	.90	.98	.98	.98	.98
Rosazeine	....	....	....	....	....	....	....	....	....	07	.54	.90	.95	.95
Iodine (dense)	....	....	....	....	....	....	....	....	....	....	.01	.03	.11	.23
Rhodamine B	.81	.71	.45	.13	.02	....	....	.23	.83	.96	.96	.96	.95	.94
Acid violet	.84	.76	.68	.50	.33	.26	.27	.34	.49	.70	.84	.96	.96	.96
Acid violet	.29	.08	.01	....	....	....	....	.01	.09	.32	.63	.84	.94	.94
Cyonine in alcohol	.07	.01	....	....	....	....	....	....	....	....	....	.01	.13	.23
Xylene red	.39	.23	.01	....	....	....	....	.01	.27	.79	.97	.97	.97	.96
Xylene red	....	....	....	....	....	....	....	....	.01	.31	.79	.96	.96	.95
Methyl violet B	.25	.04	....	....	....	....	....	....	....	....	.03	.26	.63	.89

TABLE IX.

Spectral Transmission Factors of Faded and Unfaded Gelatine Filters.

	0.44μ	0.46μ	0.48μ	0.50μ	0.52μ	0.54μ	0.56μ	0.58μ	0.60μ	0.62μ	0.64μ	0.66μ	0.68μ	0.70μ
Erythrosine	.81	.52	.14	.02	....	.02	.16	.65	.95	.96	.96	.96	.96	.96
Erythrosine (faded)	.76	.58	.27	.10	0.02	.07	.34	.78	.94	.95	.95	.95	.95	.95
Aniline yellow fast S	.51	.57	.66	.82	.94	.97	.98	.98	.97	.97	.97	.95	.93	.91
Aniline yellow fast S (faded)	.58	.62	.67	.81	.90	.95	.95	.95	.95	.95	.95	.95	.92	.90
Neptune green	.21	.41	.44	.40	.28	.15	.04	....	....	....	....	....	.06	.35
Neptune green (faded)	.10	.60	.75	.65	.43	.15	.02	....	....	....	....	....	....	.12
Green for screens	.15	.34	.72	.93	.93	.83	.69	.45	.25	.12	.04	.05	.26	.6
Green for screens (faded)	.15	.38	.70	.89	.86	.77	.67	.48	.32	.19	.09	.13	.42	.73
Ethyl violet	.74	.69	.33	.03	....	....	....	....	....	....	.06	.40	.72	.83
Ethyl violet (faded)	.67	.53	.34	.12	.02	....	....	....	....	.02	.21	.54	.77	.85
Methylenblau	.79	.75	.59	.43	.27	.11	.03	.01	....	....	....	.01	.13	.44
Methylenblau (faded)	.58	.49	.40	.29	.19	.15	.10	.09	.09	.11	.22	.35	.46	.57
Rosazeine	.97	.97	.96	.77	.54	.31	.17	.91	.95	.96	.98	.98	.95	.94
Rosazeine (faded)	.97	.97	.96	.89	.72	.73	.79	.92	.95	.95	.98	.98	.95	.94

earth's surface or in artificial illuminants as commonly encountered is open to criticism. Spectral analysis has not been sufficiently utilized in permanency tests to warrant all the conclusions which have been drawn in this matter, although some excellent work has been done.[7] Mr. Mott has shown that the results with the "snow-white" flame are in dye-fading are practically the same as those obtained in daylight.

APPLICATIONS OF SPECTRAL ANALYSES OF DYES.

The uses for spectral analyses of dyes are manifold, as in the case of any class of colored media. In general they provide a physical basis for systematic color-mixture, besides providing the necessary information for choosing dyes for many purposes. In many aspects of color-technology only the integral or subjective color is finally of interest, but the author cannot refrain from emphasizing that even in such cases an intimate knowledge of colored media and their mixtures cannot be attained without spectral analyses, and that the combination of dyes becomes systematic with such data available.

With spectrophotometric apparatus well maintained, a complete spectral analysis can be made in about an hour, although there is much room for improvement in such apparatus which will result in the saving of time. However, this is not a serious matter, because for a given coloring material only one analysis need be made, as will be shown later, to provide information for all degrees of concentration or depth of solution. The author has available hundreds of spectral analyses which, after once obtained, are a perpetual source of information.

Laws.—In order to simplify the study of coloring media, especially dyes and colored glasses, several simplifications have been made. These are based on theory and have been confirmed by experiment on a few typical specimens. In order to develop this procedure it is necessary to revert to some of the established laws. Lambert first stated that all layers of equal thickness of a transparent medium absorb equal fractions of the radiant energy which enters them. This is true for homogeneous or monochromatic radiation, but cannot be applied to the total absorption of radiant energy of many wave-lengths or of extended spectral character. It follows from Lambert's law that if the thickness of the absorbing medium increases in arithmetical progression the radiation transmitted should decrease in geometrical progression.

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[7] W. R. Mott, *Trans. Amer. Electrochem. Soc.*, 1915.

Let J be the intensity of radiation of a given wave-length entering a layer dl, then—

$$-\frac{dJ}{dl} = kJ$$

On integrating this we obtain:

$$J = J_o e^{-kd}$$

where J_o is the original intensity, J the intensity after traversing a thickness d, and k is a constant depending upon the substance and upon the wave-length of the radiant energy. Various terms have been applied to this factor, such as absorption-coefficient. In logarithmic form this equation is expressed as:

$$\text{Log}\,\frac{J}{J_o} = \log T_\lambda = -k_\lambda d \log e = -\epsilon_\lambda d$$

where T_λ is the transmission factor for energy of wave-length λ, and the subscripts, λ, indicate the factors which vary with the wave-length. Beer deduced the law that the absorption is the same function of the concentration of a dispersing absorbing substance as of the thickness of a single substance, which may be expressed thus:

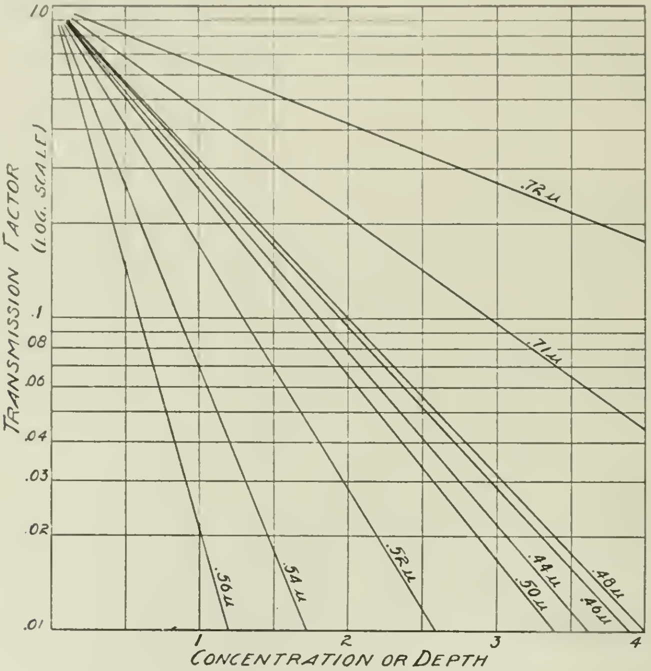
$$J = J_o A_\lambda^{cd} \text{ or } T_\lambda = A_\lambda^{cd} \text{ or } \log T_\lambda = cd \log A_\lambda$$

where c is the concentration, A is the transmission-coefficient or transmissivity, and the other symbols represent the same factors as in the foregoing equations. The validity of Beer's law has been questioned by some, and it appears that there is some doubt as to its validity in such cases as colloidal solutions. This law appears to hold when the absorbing power of a molecule is uninfluenced by the proximity of other molecules. Obviously, if any change takes place in the condition of the dispersed substance on altering the concentration the law will not hold. Incidentally there is work to be done on the validity of this law in the cases of "colloidal" glasses. Lambert's law appears to be firmly established.

In so far as the foregoing laws are valid (and it appears that this is true for all practical purposes such as described in this paper), for a given solution $\log T_\lambda$ is proportional to d, and for a given depth, or containing cell, $\log T_\lambda$ is proportional to c. By the use of coördinate paper having a logarithmic scale along one axis and a uniform scale along the other a great deal of interesting data can be obtained from one spectral analysis.

By means of the foregoing mathematical relations the spectral analyses of colored solutions (and colored glasses) of any thickness and concentration can be obtained from two determinations of spectral character, which often may be reduced in actual practice to a single determination. Such a method has been found exceedingly practicable in preliminary reconnoitering in search of combinations of dyes for filters, in the development of colored glasses, and in the study of many problems arising in color-technology.

Fig. 10.



Relation between spectral transmission-factor and depth or concentration of a solution of methylengrün.

Some examples will suffice to illustrate the uses of this scheme in practice. Assume a solution of methylengrün of either known or unknown concentration. A cell of a known thickness is filled with the solution and a spectral analysis is made. For such a purpose a fairly low concentration or small depth is chosen, so that radiations of all wave-lengths which are of interest are appreciably transmitted. On logarithmic paper, as previously described, a plot is made, as shown in Fig. 10, the transmission factors [8] from the spectral analysis being plotted on the logarithmic scale vertically above the arbitrarily selected point on the abscissa axis in this case taken as unity. The abscissæ scale may represent either concentration or depth and may be either a relative or an absolute scale. Straight lines are drawn through the points to a common point on the ordinate axis representing complete transparency or unity on this logarithmic scale. This is the common point if corrections have been made for surface reflections in the cell or from the glass surfaces in the case of a colored glass. If these corrections have not been made, the common point usually will be near 0.92 on the " transmission axis " if two surface reflections must be accounted for. Each straight line represents the relation of log T_λ and depth or concentration for a certain wave-length. By extending these lines the spectral characteristic of any depth or concentration may be read from the corresponding vertical line. If the original spectral analysis has been made with care, such a simple plot yields a vast amount of data.

Dichromatism.—Methylengrün has been chosen in Fig. 10 because it also illustrates the interesting case of dichromatism so commonly exhibited by dyes. It is seen that the slope of the line for 0.72μ is less than any of the others. This is proof that the dye is a dichroic. Some lines are very steep, which indicates a large value of the absorption-coefficient for radiation of these wave-lengths. From the plot it is seen that this dye, in solutions of high concentration or of great depth, will not be green, but will be red.

Another interesting plot, of a similar nature, but including relative luminosity-values instead of transmission factors, is shown in Fig. 11 for rosazeine. The spectral transmission factors for the spectral analysis used were multiplied by the visibility of radiation in each case (using Nutting's data) and plotted vertically above the point designated by unity on the concentration or depth scale. Instead of drawing straight lines representing various wave-lengths to a common point on the ordinate axis, each line is drawn to a point of this axis corresponding to the relative visibility of radiation of the particular wave-length. The

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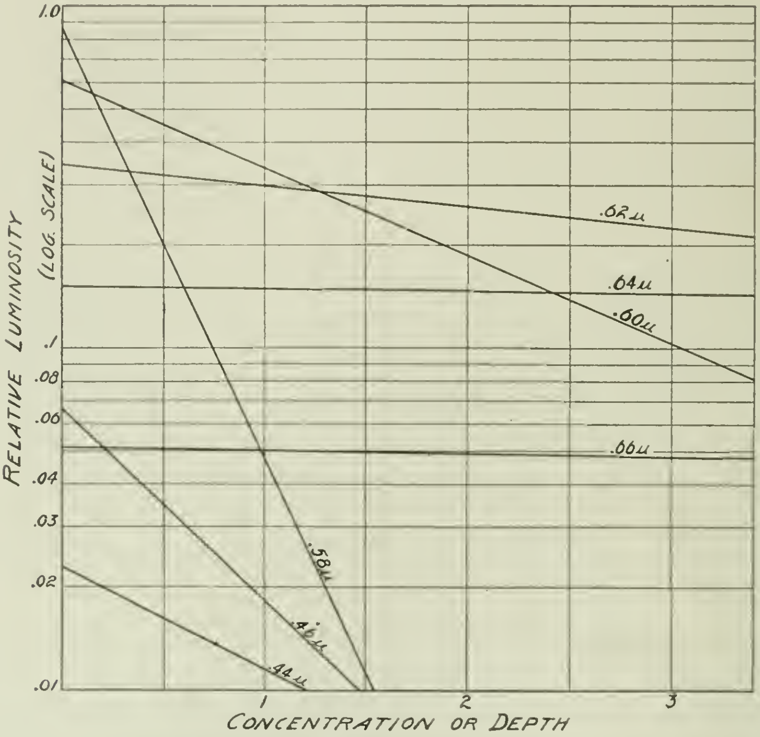
[8] NOTE.—Transmission factor is defined by the Illuminating Engineering Society as the ratio of the transmitted to the incident flux. In the present use the surface reflections are eliminated in order to make the data more useful, so that the same definition applies here for the given thickness if the body is assumed to be immersed in medium of the same refractive index.

ordinate axis is now a logarithmic scale of relative luminosity. By extending these straight lines a graphical picture of spectral luminosity of the dye-solution is obtained for any concentration of depth. It is seen that this solution in great depth or high concentration becomes deep red, because the slopes of the lines become less with increasing wave-length after the absorption band of a weak solution or small depth is passed. Incidentally it will be noted that the slope of line 0.44μ is less than that of 0.58μ, which shows that in low concentrations or in relatively small depths of a higher concentration the solution is purple; that is, it has an absorption band somewhere between 0.44μ and 0.60μ. Only a few wave-lengths have been used for the sake of clearness.

Fig. 11.



Relation between spectral luminosity and depth or concentration of a solution of rosazeine.

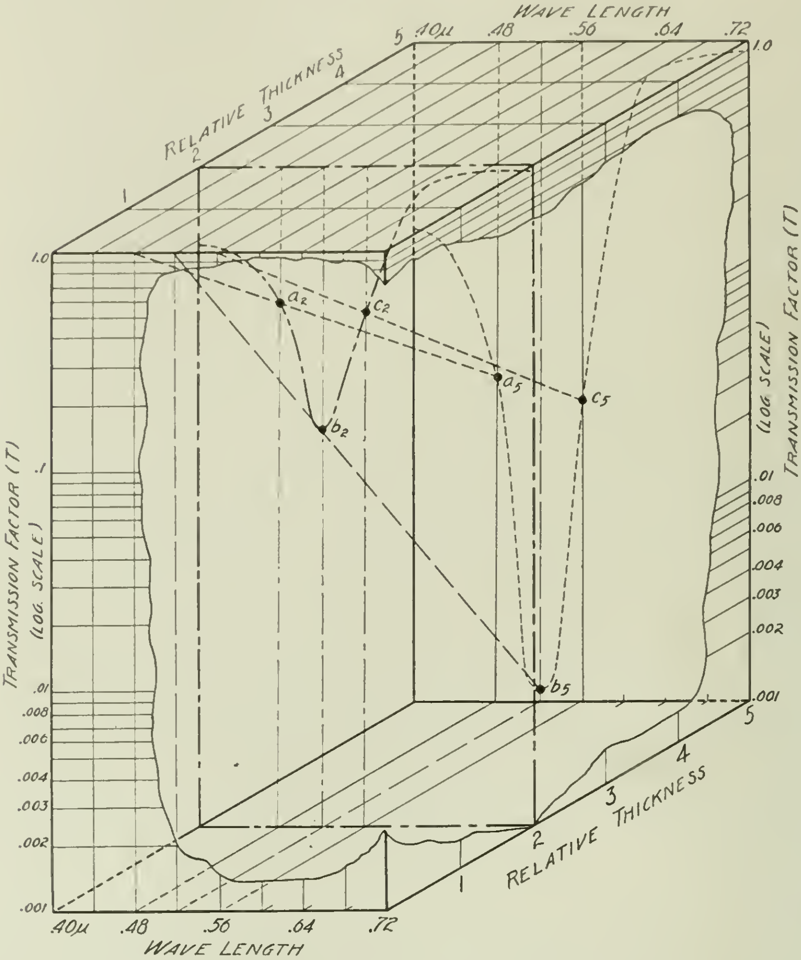
Complete Representation of the Graphical Method.—In reality the schemes illustrated in Fig. 10 and 11 are only completely illustrated by means of a solid, of which, for example, Fig. 10 represents a projection upon the face of the solid bounded by the logarithmic "transmission" scale and the concentration or depth scale. A model of this tri-dimensional diagram can be easily made and should be instructive. An attempt is made in

Fig. 12 to illustrate the relations between transmission factor, wave-length, and concentration or thickness. For this purpose the spectral analysis of a thin piece of gold red glass was chosen. Many of the cross-section lines have been omitted for the sake of clearness. The scales are designated and the thickness of the specimen of gold ruby glass is assumed to be 2 units on the relative thickness scale. In plane 2, represented by the dash-dot vertical rectangle, the spectral transmission is shown in the dash-dot curve, $a_2b_2c_2$. For the limiting case of zero thickness this curve becomes a straight line, $T = 1$, which is the top edge of the foremost rectangle, plane 0. Several points of the "master" curve in plane 2 were taken for the purpose of illustrating the determination of the spectral characteristic of the glass at another thickness. In this example thickness 5 units is taken and its spectral transmission is shown by the dotted curve in plane 5, the farthest vertical rectangle. This curve is obtained by drawing straight lines in the "wave-length" planes from the wave-lengths on the upper front scale through the points on the "master" curve in plane 2 of corresponding wave-lengths. Thus where a given straight line intersects the various thickness planes the transmission factors for that wave-length are found. For example, b_2 is a point on the "master" curve in plane 2, and its value as read from the transmission scale is the transmission factor of this specimen of thickness, 2 units, for radiation of wave-length 0.52μ. A straight line drawn through this wave-length on $T = 1$ and through b_2 (always remaining in the particular wave-length plane) when prolonged intersects plane 5 at b_5, which is the transmission factor for 0.52μ for a specimen of the same glass of 5 units thickness. Other points, a_5, c_5, etc., are found in the same manner.

These straight lines are the same as those shown in Fig. 19; in fact, Fig. 19 would be seen on viewing the solid, Fig. 12, from the right-hand side. A model of this solid made of wires and painted to represent the spectral colors should be instructive.

In Fig. 11 luminosity values were treated in a manner similar to the transmission values in Fig. 10. These also can be completely represented by a solid in a manner similar to that shown in Fig. 12, excepting that the vertical scale must represent logarithms of luminosity. In the limiting case of zero thickness the curve will not be the foremost upper horizontal line, but will be the spectral luminosity curve of radiation and will lie in the foremost vertical plane On viewing such a solid in projection from the proper side, Fig. 20 will be seen if the same gold ruby specimen be taken as an example. It appears unnecessary to illustrate this possibility, since the general procedure should be understood from the foregoing. In case the analysis is to be made for a

Fig. 12.



Complete relation between thickness, wave-length, and transmission-factor for a gold ruby glass.

particular illuminant the limiting curve in the foremost vertical plane will be the luminosity curve of the illuminant.

One of the points which is emphasized in dealing with colored media in the foregoing manner is that the spectral transmission and reflection factors are never zero, but are merely relatively low for some wave-lengths as compared with others. This is often forgotten when spectral analyses are made with instruments, because when the luminosity falls below the threshold the transmission factor is considered to be zero; however, the threshold depends upon the intensity of illumination or upon the brightness of the light-source.

SPECTRAL ANALYSES OF GLASSES.

In the development of colored glasses for the variety of practical applications the spectral analyses are extremely valuable and often essential. By means of such data these coloring elements can be mixed computationally to obtain the desired spectral characteristic. From very meagre data on the chemical composition from one melt fairly definite strides toward realization may be made in succeeding melts. Of course, there are chemical considerations which sometimes alter the predictions based on computation; however, such a procedure forms a most definite working basis. In the combination of glasses for special filters, lighting effects, etc., the computational method often saves time and provides definite data. Sometimes only the subjective color is desired, but even in these cases spectral analyses of elemental colorings provide the basis for manipulating the available vitrifiable colored media in a manner analogous to the combination of pigments.

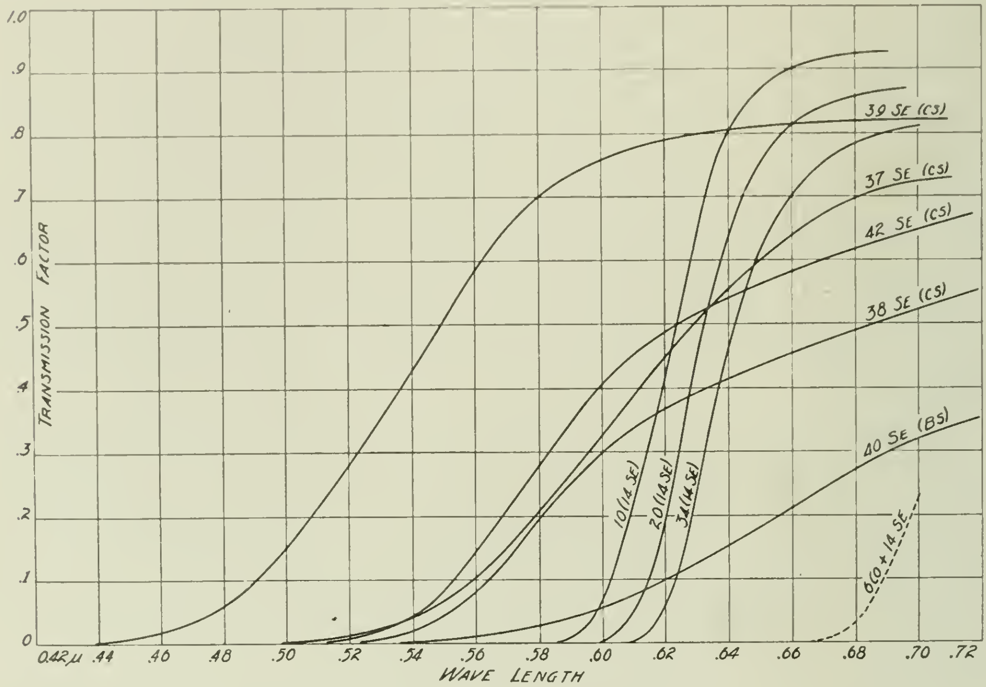
In the manufacture of colored glass there is a limited number of coloring materials available, and when the glass must be limited to one general composition, such as soda lime, for example, the colors which are possible of attainment are further limited. However, by combining various coloring materials the variety of colored glasses can be enormously extended to meet the requirements of science and art.

In this paper the spectral analyses of a few fundamental colored glasses will be presented, and also the results of a few simple combinations. The record number of the specimen is placed before the symbol of the coloring metal, such as 37 Se. If different relative thicknesses of the specimen are presented, a number is placed before the designation proper, as 10 (37 Se) indicates 10 units of thickness (or of concentration), CS indicates lime soda glass, PS lead soda, BS barium soda, P lead, etc.

Red.—Selenium, copper, and gold are commonly used for producing red glasses. In Fig. 13 are shown the spectral analyses of a number of selenium glasses. It is seen that some of these are yellow in appearance and vary from this to a deep red. The composition of the mix is sometimes of considerable influence upon the final color. Specimen 14 Se, shown in relative thickness, 10, 20, and 34, was of unknown composition, but the coloring element was selenium. This is a remarkable specimen. Cobalt blue glass (Fig. 17) transmits a deep red band, so a combination of dense cobalt blue and selenium glasses isolates a deep-red band, as seen in 6 Co + 14 Se, Fig. 13.

By computations similar to those presented in the case of pigments (substituting transmission factors, T_λ, for reflection factors R_λ) the efficiency of such a combination in transmitting only a deep-red band can be compared with that of a very dense selenium, gold, or copper glass. Unfortunately, at the ends of the visible spectrum the visibility data are difficult of determination and have been the least investigated; however, Hyde, Cady, and Forsythe[9] have determined the visibility at the extreme red end of the visible spectrum with great care.

Fig. 13.



Spectral transmission-factors of selenium glasses.

In Fig. 14 is shown the spectral characteristic of a copper-red glass, 4 Cu, and in Fig. 15 the spectral analyses of gold glasses are presented. Gold produces a beautiful pink in low concentrations (or in thin layers) and deep red in the higher ones (or

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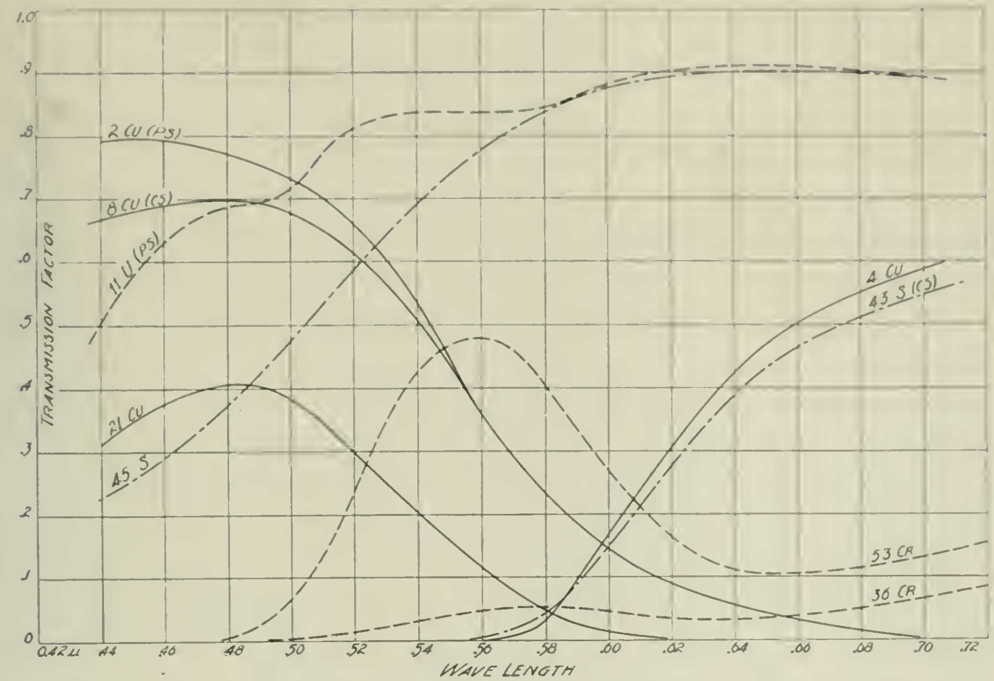
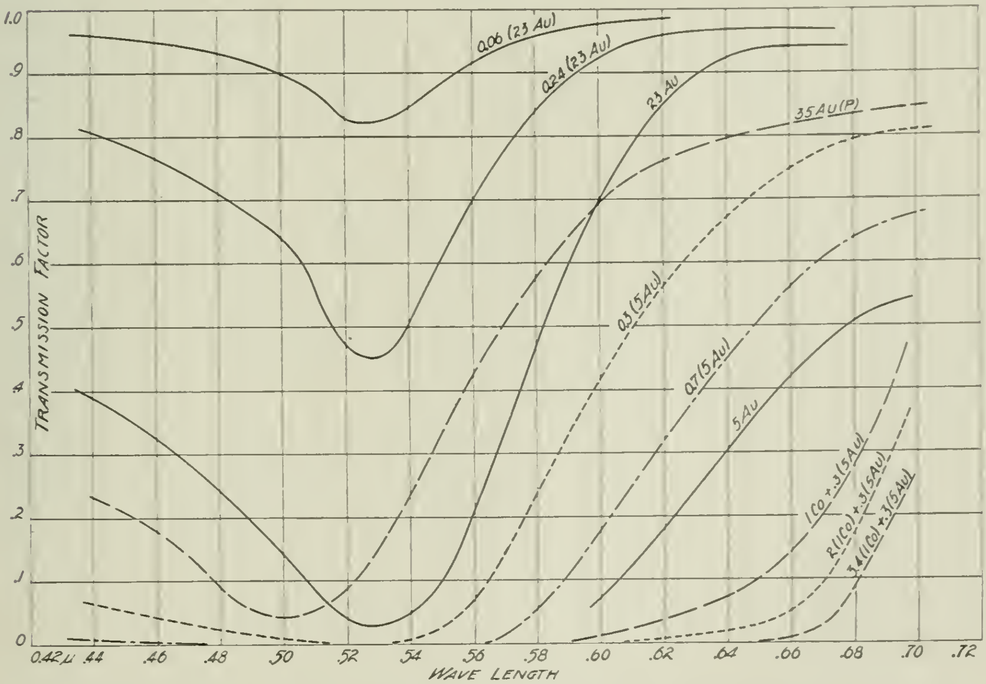
[9] *Astrophysical Journal,* 42, p. 285, 1915.

FIG. 14.



Spectral transmission-factors of copper, sulphur, chromium, and uranium glasses.

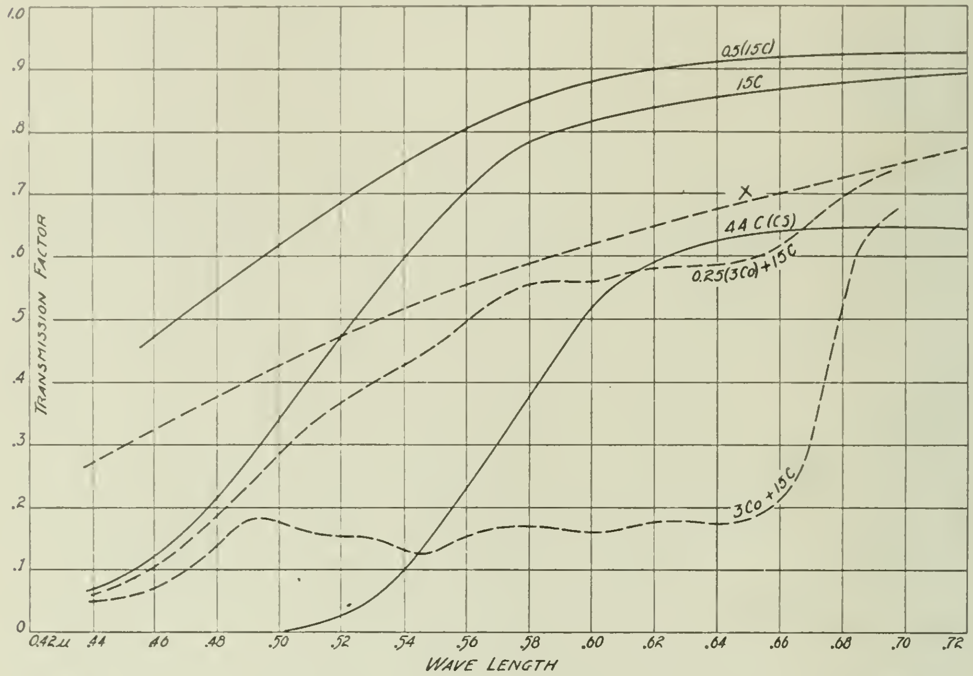
FIG. 15.



Spectral transmission-factors of gold glasses and combinations of cobalt.

in thicker layers). The absorption band is seen to be near 0.53μ for the more transparent glasses, and it is interesting to note glass 35 Au, a lead gold, which shows a shift in the absorption band to 0.50μ. This glass was reheated several times in bringing out the color, which is decidedly more ruddy, and it appears that there is a different state of division of the metallic particles, perhaps, as to size. As the concentration or thickness increases (glass 5 Au, which is shown for three thicknesses) the blue band gradually disappears; however, the transmission does not closely approach monochromatism. In Fig. 15 are also shown

Fig. 16.



Spectral transmission-factors of carbon glasses and combinations with cobalt glasses.

the results of combining cobalt and gold glasses of different thicknesses (or concentrations), with the resulting transmission confined to the deep-red region.

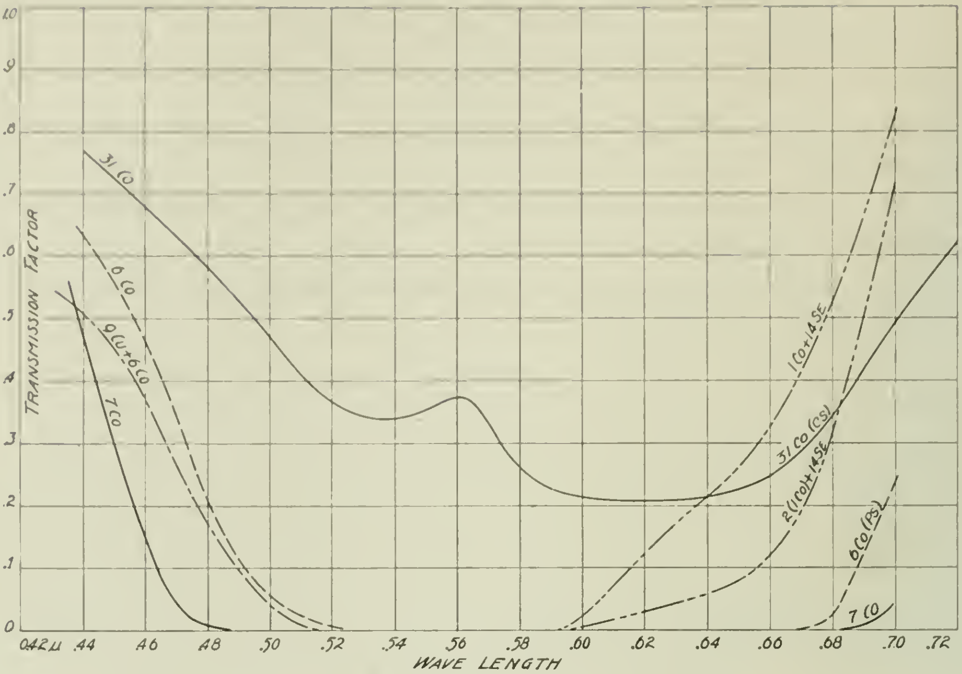
Yellow.—Carbon, sulphur, uranium, and silver are among those elements which, when introduced into glass under proper chemical conditions, produce yellow glasses of varying color. No single element isolates spectral yellow. In Fig. 16 are shown the spectral analyses of carbon yellow glasses, 15 C and 44 C, and of combinations of carbon yellow and light cobalt blue glasses. It is known that X-rays, ultraviolet and visible rays will cause some clear glasses to become colored. In Fig. 16 is also shown the spectral characteristic of a glass *X*, which, though originally clear, was colored a muddy yellow throughout the mass by X-rays. It is interesting to observe the action of X-rays in discoloring glass, for it is easy at times to observe the progress of the coloring through the thickness of the glass. Patterns can be made by this process. In Fig. 14 are shown the spectral characteristics of uranium (11 U) and sulphur (43 S and 45 S) glasses. The spectral transmissions of several uranium samples appear to be kinky in the blue-green region, although the exact nature of the curves are not established.

Green.—Iron imparts a green color to glass, varying from a bluish to a yellowish-green, depending upon the ingredients of the glass. The importance of manganese in glass is as a decolorizing agent, its color in proper concentrations being roughly complementary to that of iron commonly present in sand. Chromium imparts a yellowish-green color to glass, as seen in glass 53 Cr, Fig. 14. This glass has a maximum transmission at about 0.56μ, and by the addition of copper blue-green (glasses 2 Cu and 8 Cu, Fig. 14) this maximum can be shifted toward the shorter wavelengths, depending upon the proportions of the coloring elements. Glass 21 Cu, called signal blue-green, is evidently a copper glass. Glass 36 Cr is a dense chromium green. In order to compare the actual colors under a given illuminant it is well to reduce these curves to luminosity values. If monochromatism is desired, it is often advisable to combine two glasses which transmit a narrow region in common.

Blue.—Cobalt is the most common element used to impart a blue color to glass. Its greatest disadvantage (although sometimes an advantage) is its transmission of a deep-red band, as shown in 6 Co and 7 Co, Fig. 17. This red transmission can be utilized in isolating the deep red, as shown by combining cobalt and selenium or other red glasses, for example 1 Co + 14 Se. An excellent blue glass can be made by combining cobalt with copper blue-green, for the latter effectively absorbs the deep red. The spectral characteristic of such a combination is shown in 9 Cu + 6 Co, Fig. 17.

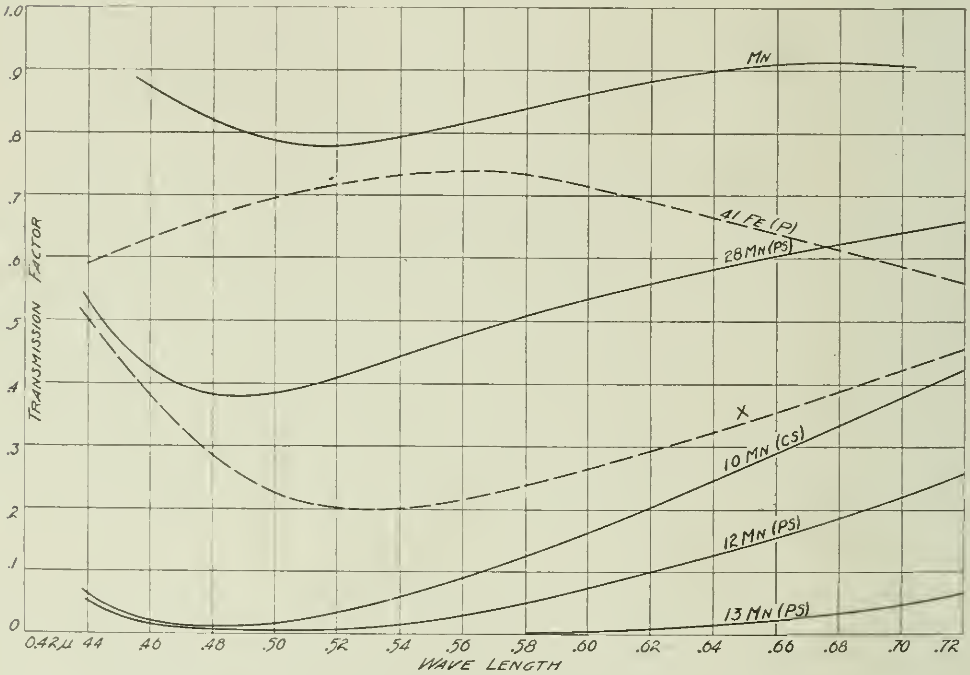
Purple.—Nickel produces a purple color in glass, and also manganese, but the latter is not an efficient purple, because its absorption band is not sharp. Its chief use is to neutralize the green tint due to the presence of iron in the ingredients of glass

FIG. 17.



Spectral transmission-factors of cobalt glasses.

FIG. 18.



Spectral transmission-factors of manganese and iron glasses.

mixes. The spectral characteristic of a glass containing iron is shown in 41 Fe, Fig. 18. It is seen that a manganese glass of proper density is approximately complementary in color to the iron glass. Although the manganese neutralizes the iron in color, the transmission factor of the resultant glass may be seriously reduced. Manganese, though a useful element in glass manufacture, cannot be considered important as a coloring element from the viewpoint of colored glass in general. In X, Fig. 18, is shown the spectral characteristic of an originally clear glass which has been colored a deep-purplish hue by exposure to X-rays. Undoubtedly this coloring is due to an effect upon the manganese present in the clear glass. This effect is commonly observed in lamp globes and window glass exposed to strong sunlight. In the former cases it is a very serious defect of glass manufacture, because the author has observed such globes whose transmission has been reduced as much as 50 per cent. after long exposure to intense solar radiation or to that emitted by an arc lamp. It would be far better in such cases as street-lighting glassware to eliminate the manganese and to endure the unneutralized greenish hue of the iron which is unavoidably present.

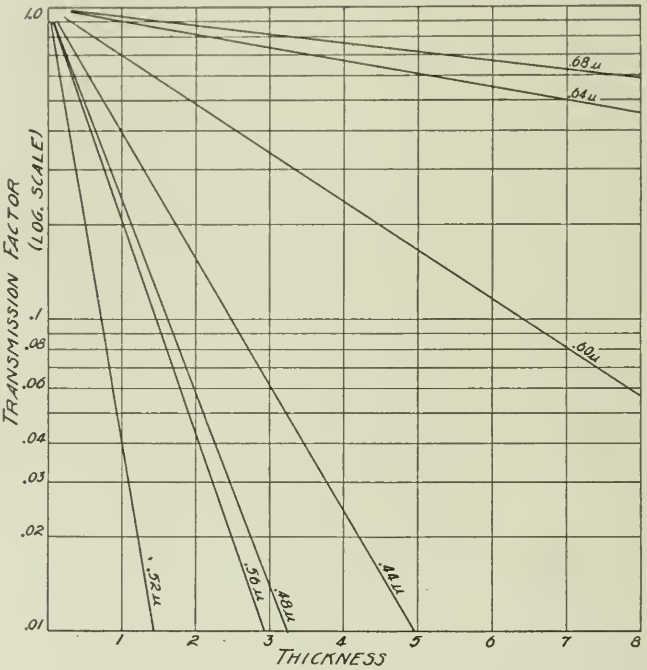
USES OF SPECTRAL ANALYSES OF GLASSES.

The applications for spectral analyses of colored glasses have been fairly well covered in the discussions of pigments and dyes, for the same general procedures can be applied to colored glasses. The concentration is not so definite as in the case of dyes, because, owing to the high temperature at which glass melts and to chemical action, the concentration of coloring material in the final glass cannot always be predicted from the amount of the coloring metal added to the mix. Some of the metals, such as cobalt and copper, under standardized conditions of melting, appear to produce concentrations of coloring material proportional to the amounts of the oxides added to the mix, but in some cases there is doubt as to this proportionality. There is need for systematic study in this direction. In the case of the red glasses, for example gold ruby, which in ordinary manufacture assumes its red color on reheating, the manipulation has considerable effect upon the density of the color. After a colored glass has been obtained it is possible to procure from a single spectral analysis the integral transmission factor for any illuminant, the spectral characteristics of other thicknesses, and those of combinations of these thicknesses with other colored glasses as already outlined.

For the sake of further exemplification, in Fig. 19 are shown the straight-line relations between thickness and transmission factor (for entering radiation) for several wave-lengths for various thicknesses of a gold ruby glass. The relations between luminosity and thickness for this glass are shown in Fig. 20 for various wave-lengths. Fig. 19 is a diagram of what would be seen if the solid represented in Fig. 12 were viewed from the right-hand side.

At this point it is of interest to show the approximation of experimental results to the relations between spectral character and thickness as predicted by theory. This is shown in Fig. 21 for one of the glasses made during the development of an "artificial-daylight" glass some years ago. The method of graphical analysis was tested because of the desire for a simple method, and the specimen was ground and polished in five thicknesses. The circles show the verification of the theory. In this case correction had not been made for surface reflection, so the straight lines must be drawn to a point near 0.92 on the transmission axis. Incidentally it is of interest to note that, previous to the adoption of this method, samples of melts were ground in the form of thin wedges and spectral analyses were made at various thicknesses. It is seen that the graphical method enormously reduces

Fig. 19.

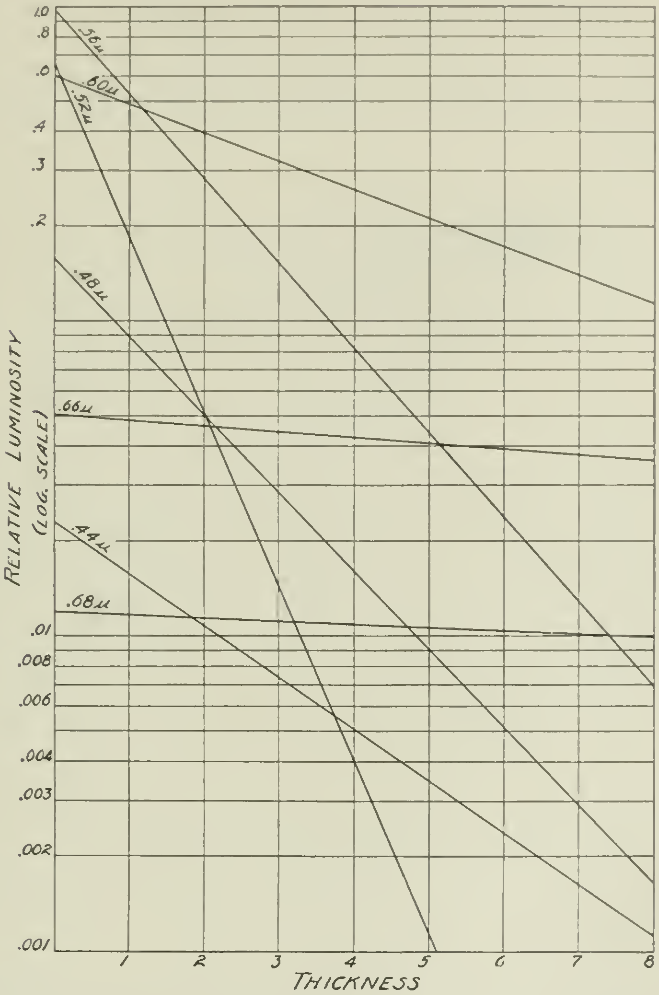


Relations between spectral transmission-factor and thickness of a gold glass (23 Au).

the amount of work in order to obtain the data necessary for such studies.

In developing a colored glass for a specific purpose various factors are considered, such as the illuminant to be used and the result to be obtained. From these an ideal spectral transmission curve is determined, and by means of a few spectral analyses of different colored glasses, bearing in mind the chemical considerations if a mixture is finally necessary, various combinations can be made with the aid of the graphical method.

Fig. 20.



Relations between spectral luminosity and thickness of a gold glass (23 Au).

Often the ultraviolet and infra-red spectral transmissions are of interest, and these are made in the manner already described. The data on a coloring element are not considered to be sufficiently complete for record if the ultraviolet transmission is not studied at least qualitatively, and in some cases the infra-red transmission is investigated. It appears unnecessary to discuss these further, for the aim of this paper has been realized. Various data have been presented with the hope that they will be helpful to others, and various uses of physical data have been discussed with a view to presenting only aspects that are uncommonly appreciated and which have been developed in practical work in color-technology.

SUMMARY.

There have been presented in the foregoing:

A discussion of methods of analyzing color.

A discussion of general characteristics of pigments, dyes, and colored glasses.

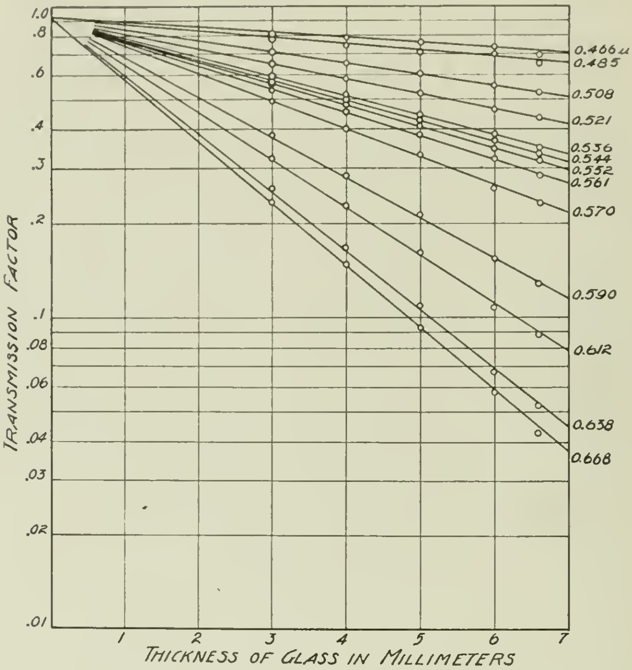
Laws of absorption and their uses.

Spectral analyses of the visible radiation reflected by pigments and transmitted by dye-solutions and colored glasses.

A discussion of the uses of such data.

A general emphasis of the importance of a physical basis in color-technology.

Fig. 21.



Test of the relation between spectral transmission-factor and thickness of a blue-green glass.

I wish to acknowledge the assistance of Mr. H. H. Kirby in obtaining the data and preparing the illustrations.

Cleveland, Ohio,
April 28, 1917.

SUBMARINES IN PERIODICAL LITERATURE FROM 1911 TO 1917.

COMPILED BY

HELEN R. HOSMER.

Introduction
- I. *General*
  - History of Development
  - Military Considerations
  - Dimensions
  - Specific Boats
- II. *Propulsion*
  - Engines
  - Storage Batteries
- III. *Armament*
  - Torpedoes
  - Guns
- IV. *Special Equipment*
  - Periscope
  - Signalling
- V. *Builders*
  - Boat Builders
  - Engine Builders
- VI. *References*

INTRODUCTION.

In this outline of publications discussing the submarine, an attempt is made to present the general status of current knowledge on the subject rather than give detail. At the same time such exact data are included as might be required by the person who, approaching the problem as a stranger, may wish to get an idea of the magnitudes involved. More exhaustive inquiry will always demand consultation of the original publications, to which this paper may, in that case, serve as an index.

No material is given here that is not quoted directly from the references under consideration. Where ambiguity has existed, the form of expression also has been followed rather than risk further error by imposing the interpretation of the compiler.

Many short notes and general papers have been omitted from notice when it has seemed that they would not add value to the collection.

Also, none of the many articles appearing in the *Scientific American* have been quoted. This last is for the reason that such articles generally contain exactly the same data that are found in the technical papers, and in an already abstracted form. Where other library facilities are lacking, a very great deal of information may be gained by the consulting of the files of this journal.

I. GENERAL.

History of Development.
Military Considerations.
Dimensions.
Specific Boats.

Bedell[1] (1917) gives a general description of the gross characteristics of the submarine and a brief history of its development. He mentions that vision from the periscope through the water, in the clearest water, does not exceed 100 to 200 feet. In the turbid waters along our shores nothing can be seen 75 feet away.

Kearney's[2] (1915) article is very general in nature and intended to amuse rather than instruct. He outlines the development and purpose of the submarine.

Hinkamp[3] (1915) gives the principal dates in the development of the submarine, and then goes on to a general description of the methods employed in operation. No specific data are included.

In reference[3] (2) (1915) Hinkamp mentions the improvements made since the early days of the submarine in each of its most prominent features.

Woodhouse[4] (1917) states that vision downward from an aeroplane is not affected by the refraction that limits that from a ship. At an elevation of 1000 to 1500 feet the wake of the periscope is plainly visible against the dark water, even when there are white-caps. In clear weather the submarine can be seen at depths from 20 to 100 feet, depending upon the clearness of the water. The foamy wake at the stern is also clearly visible. Painting will not obscure this last. Hundreds of kite balloons sent up from ships are being used as outlooks for submarines.

Lake[5] (1915–1916) introduces a paper upon the future possibilities of the submarine by an historical account of its development. This goes back to Bushnell's American turtle, and gives considerable detail on the construction and operation of subsequent types. The United States Government first recognized the possibilities of the submarine in 1893 by appropriating $200,000 for building such a boat. Holland's *Plunger* was the result, which failed to meet the requirements of a guarantee such as has never yet been met by any submarine. She never made a submerged run. A great deal of detail concerning the construction and principles affecting operation is given. The problems solved in the building of Lake's *Argonaut* and other contemporary boats are gone into in detail.

Lake[5] believes coast-defence submarines will be found especially valuable. Speed and high tonnage will not be necessary. A boat of 500 tons displacement and a speed of 14 or 15 knots can have comfortable living quarters and carry eight Whitehead torpedoes. Such a boat can be built for one and one-half million dollars. These boats should be equipped to fire in any desired direction submerged. The *Seal* (G-1) is the only one thus far equipped with torpedoes that can be fired to either broadside. If such submarines were stationed at intervals of five miles outside New York Harbor, no ship could pass without being seen by day or heard by means of the Fessenden oscillators or microphones, with which all submarines are now equipped. As these microphones enable code communication up to several miles, the submarines could be in constant communication with each other and with the shore.

Lake believes that the near future will see the building of a high-speed submarine for offensive warfare, equipped with rapid-fire guns of sufficient calibre to deal with merchantmen and with room enough in the superstructure to keep a crew in good condition during a long cruise. This should be capable of at least 25 knots. As the engine situation stands to-day Lake does not believe such a boat of even 20 knots can be developed in less than three or four years. This is due to the fact that no internal-combustion engine suitable for such high speeds has yet been produced. There is no difficulty connected with the functioning of the vessel itself.

Lake suggests the building of 250-ton (submerged displacement), 10-knot submarines, capable of transportation on railroad trucks, for coast defence. These would be somewhat smaller than the present coast-defence submarines, and could be transported rapidly to any threatened point of our extended seaboard. This would give them a range much greater than possible with our present submarine fleet, of which the best have a radius of action of about 100 miles at five knots, 11 miles at ten and one-half knots, or 24 miles at eight knots. He states that these "amphibious" submarines could be built at a cost of about $300,000 each.

Lake considers that the proposed one man "baby" submarines would, on account of their low speed, limited range of action, and unseaworthiness, be of very little use to-day.

Lake [5] believes that, as it is impossible to see the invisible, submarine cannot fight submarine, and says that, infested as have been the North Sea and English Channel, he knows of no one case where one has succeeded in sinking another. An Austrian submarine did sink an Italian, but the latter was surface cruising.

Lake [5] dismisses as absolutely impracticable the idea that a submerged submarine can be located by an overhead aeroplane, much less successfully attacked, even if so located. He also considers the efficacy of nets as very doubtful. They could be easily evaded by submarines suitably equipped. He mentions at length a mine-laying submarine which he designed and built, but which the government failed to adopt.

Lake [5] states that in the light-surface or decks-awash condition the submarine may sight a ship at ten miles. The periscope at rest is invisible from a ship one-half mile away.

The internal-combustion engines used in surface cruising are very noisy, but the storage battery and motor are practically noiseless.

The United States submarine *Seal,* or G-1, as originally equipped, is the only vessel ever built in the United States with torpedo tubes to fire broadside. She had four torpedo tubes which could be trained and fired to either broadside, both submerged and on the surface. This would enable her to lie at rest and fire, thus eliminating the tell-tale wake of a moving periscope. A periscope of neutral color at rest is almost impossible of detection even at 300 to 400 yards.

Lake intimates that he has devised certain other improvements and tactics as well as methods of protecting ships that it would be unwise to publish.

Laubeuf [6] (1915) explains in detail the differences between the submarine of the earlier type and the submersible, and gives cross-sections showing the hull construction of the Holland, Lake, Electric Boat Company's, and French Maugas system submarines, and of the Laubeuf, Germania-Krupp, and Laurenti submersibles. Dimensions, displacements, and values of reserve buoyancy are given for each. If the coefficient of reserve buoyancy be defined as the ratio of the reserve buoyancy (equal to the emerged volume of a surface boat) to the total volume of the ship completely immersed, this coefficient is 50 per cent. for ordinary ships, 3 to 7 per cent. for the earliest submarines, 12 to 13 per cent. for the pure submarine type, and 27 to 33 per cent., or even 41 per cent. for the Laubeuf type of submersible. This means that, on the open sea, the last navigates the surface like an ordinary boat, while the submarine, pure and simple, has to withdraw her crew and navigate under the same conditions as when submerged.

The submersibles are slower of submergence, but the time required has been reduced from 28 minutes in the first Laubeuf boat to five minutes in recent boats. The last is stated to meet all military requirements.

In 1900 France was the only power possessing submersibles, and since 1907 she has ceased building any other type. Germany, Italy, Greece, Sweden, Norway, Portugal, and Brazil have followed her example. The submarine type, pure and simple, is undergoing modification and approaching the submersible. The Electric Boat Company, which has built, directly or through its licenses, the greatest number of submarines, has gone over in its new type, M, to a boat with large reserve buoyancy and a partial double shell.

Increase in displacement does not bring to the submarine a proportionate increase in offensive power. It increases the speed but at the same time causes (1) greater difficulties of evolution, submerged; (2) increase of draft preventing navigation in shallow water and easy passage under enemy ships; (3) too large a turning circle; and (4) too high cost.

Laubeuf concludes that two types of submarine are advisable in the future—the moderate tonnage and speed, coast-guard boat of good seagoing qualities, and the squadron boat of 1000 tons displacement, or more, which should have a minimum speed of 23 knots on the surface and 15 knots submerged. With a speed less than this, submarines will be merely an impediment to a fleet. The necessary step to the attainment of this speed is the realization of a single motor, powerful, reliable, and light, for both surface and submerged propulsion.

Reference[7] (1915) describes the Laubeuf submarine boat and its development. Laubeuf, the naval architect of Messrs. Schneider & Co., made the departure of fitting to submarines hydroplanes to facilitate diving. These constitute the important difference between the submersible boat and the submarine. In submarines of the ordinary type, buoyancy is comparatively low, the ratio of buoyancy on the surface to the total displacement when submerged being less than 15 per cent. In some submersibles it goes up to 22 per cent., but in the Laubeuf type it reaches 33 per cent. Consequently the last have a greater power of emergence and a higher freeboard on the surface than other types.

Especial attention is paid to the comfort of the crew.

The construction and equipment of the Laubeuf boat are described in some detail, and a table is given showing the dimension characteristics of the various classes. The French flotillas are mostly composed of these boats.

Engineering[8] (1911) outlines the development and performance of the Holland boats built by the Electric Boat Company. The number of vessels of this type in commission in the various nations and the builders working under licenses are given. It is stated that to date not a single disaster has overtaken any one of these boats which was built to the unaltered designs of the Electric Boat Company.

A table is given showing the development in size, speed, and fighting power during the ten years from 1895 to 1911. The characteristics of the "perfected" Holland are given with plans and sections. The interior arrangements, provisions for safety, submergence tests, diving mechanism, etc., are described rather fully. These boats take an angle at diving that never exceeds four or five degrees, and is ordinarily only two to two and one-half degrees. The increase of draft due to diving, in excess of that of even keel submergence, is only three to four inches.

Stability conditions are discussed briefly.

Admiral Sims[9] (1917) stated, at a hearing before the House Naval Committee, that a submarine cannot operate safely in the presence of surface boats of the enemy in less than 60 to 70 feet of water. All submarines draw about the same amount of water from the keel to the top of the periscope; that is, about 40 feet. The speed under water is eight to ten knots, and the radius 40 to 60 miles. After exhaustion of the batteries the submarine must come to the surface and stay for three to five hours. Hence most of her travelling must be done on the surface. Submerged she must keep moving or else rest on the bottom, and this last is only possible in depths less than 200 feet. When moving submerged she leaves a wake. The result of these characteristics is that a naval force commanding the surface can counteract almost entirely the effectiveness of the submarine.

The method of netting submarines is described.

Rodgers[10] (1916) takes up the military functions and recent performance of the submarine of to-day. He points out that because of its inherent peculiarities it is an arm best used by stealth and in dispersed and solitary action. Defensive measures against it, such as wire nets and counter attack by swift patrol boats, have been very successful. It is primarily a defensive arm for the weak. Its notable feats during the present war were confined to the early days before methods of warding off its attacks had been devised and it has accomplished little or nothing when acting in concert with main fleets.

No submarine, even as large as 1200 or 1500 tons, has room for the powerful machinery necessary to enable her to accompany and coöperate with the present battleship of 20 to 23 knots.

Hence the practice of the United States Navy in adhering to a 500-ton boat suitable for coast defence seems logical.

Rodgers summarizes the military peculiarities of the submarine which have limited its effectiveness.

The great percentage of displacement necessarily devoted to the heavy hulls and very heavy machinery installation and storage batteries makes armor impracticable, and reduces speed far below that practicable for surface boats of equal size. Hence its chief defence is submersibility and consequent invisibility. The submarine can see nothing when completely below the surface. She can navigate freely and recharge her storage batteries only when running her oil engines at the surface. The great weight of the storage batteries upon which all submerged cruising must be done limits her to a small radius of action when in that condition, at most 12 miles at 10 or 12 knots, or 100 miles or less at 5 or 6 knots.

Her chief armament, the torpedo, has a maximum initial velocity of 40 miles per hour over moderate distances, compared with 3000 feet per second for a light-power gun projectile and 60 feet per second for the fastest ship. Thus a 30-knot torpedo, capable of running 10,000 yards, has a chance of hitting a boat approaching at 20 knots at a range of over 16,000 yards, but will stop before reaching a boat withdrawing at the same rate, if fired at a range above 3300 yards.

Lake [5] analyzes the limitations of the present submarine that compel "sinking without warning" if it is to be effectual in commerce destroying. He shows by diagram how, owing to the necessity of firing in line with her axis, at a distance of not more than one-half mile, and against the broadside of the boat attacked, the submarine has only one and one-half minutes for effective action against a 20-knot ship. If fair warning is given there is little chance of halting the ship and considerable of the destruction of the submarine. He believes this drawback can be overcome in boats of the future by increase in speed to something approaching that of ordinary ships, and equipment with torpedo tubes to either broadside. A 15-knot submarine so equipped would have nine minutes in which to deal with a 20-knot ship.

Robinson [11] (1915), managing director of the Lake Torpedo Boat Company, gives a general treatment of the subject of the submarine in warfare; concluding with a detailed explanation of the functions and the sort of tactics advisable for each of the three types of to-day—the harbor defence, the coast defence, and the sea-keeping offensive type.

He goes into each of the principal constituent details of the submarine boat, mentions the difficulty of propeller design for both surface and submerged operation, and points out that the United States designs have been loaded down by overemphasis on safety. This last fact has increased the size and cost and lowered the effectiveness. The 200-foot submergence test is an example. All foreign navies have been content with 40 metres (131 feet), and opinion here is tending toward the adoption of the 150-foot limit.

The present type of submarine, of which the United States has a considerable number, is from 250 to 550 tons submerged displacement, has a surface speed of 12 to 14 knots, and a radius of action, at nine or ten knots, of 1500 to 4500 miles.

"The sea horizon viewed from a periscope 20 feet above the surface is just 10,000 yards. At this range the horizontal angle, subtended by a 600-foot target, is a little under one degree. When the periscope height is three feet above water the sea horizon is distant 4000 yards, and when one foot exposed it becomes 2200 yards."

"The practical difficulties of finding and then firing at specks on the horizon are so many as to compel the submarine to take advantage of her invisibility and immunity from gun-fire to push the attack to close quarters—2000 yards or less."

The "light condition" signifies that all the water ballast tanks are empty and the cruising bridge is rigged.

In the "awash" condition only those water-ballast tanks are empty which are habitually kept full when running submerged. The fore-and-aft trimming tanks and two smaller tanks, called the auxiliary tank and the adjusting tank, are filled with just enough ballast so that when the main ballast tanks are filled the boat will be immediately ready for running submerged without further adjustment of ballast. The submarine then has practically the same stability and safety as when running "light." A small section of the bridge may be kept up for the lookout, and the conning tower hatch may be kept open and the radio rigged.

In the "submerged" condition the ballast and other tanks are filled so that there still remains a small reserve of buoyancy (0 to 800 pounds) and the boat is all ready for submerged running.

Spear[12] (1915) discusses the submarine of to-day and to-morrow at very great length, classifying them as to types and tabulating the size, armament, etc., of each. He takes up the present stage of development and military status, and deduces the probable future of both. So far as known, there are, in the world to-day, about 350 submarines completed and 200 more building.

The mechanical development during 14 years is shown by a comparison of one of the first successful boats (Type A) with one of recent construction (Type B).

TABLE I.

	Type A, 1900		Type B, 1914	
	Feet	Inches	Feet	Inches
Length	53	10	230	6
Beam	10	3	21	6
Surface displacement, tons	67		663	
Submerged displacement, tons	75		912	
Horsepower, surface	50		2000	
Speed, surface, knots	6		17	
Horsepower, submerged	50		980	
Speed, submerged, knots	5½		10¾	
Radius action, surface, knots	200		3000	
Number torpedo tubes	1		8	

TABLE II.

	Type A, 1900	Type B, 1914
Horsepower main engines	50	2000
Pounds per horsepower	78	48
Fuel consumption, pounds per horsepower	.74	.50
Horsepower electric motors	50	980
Pounds per horsepower	57	48
Pounds per horsepower of storage battery	909	216

Type B is fairly representative of the best results achieved here to date, and the following comparison with boats of other navies corroborates its representative nature:

TABLE III.

	Type B		English E	German U-21-32	German U-33-42
	Feet	Inches	Feet	Feet	Feet
Length	230	6	175	213	223
Surface displacement, tons	663		730	640	665
Submerged displacement, tons	912		825	787	822
Engines	Diesel		Diesel	Diesel	Diesel
Horsepower, surface	2000		1600	1800	2300
Speed, surface, knots	17		15–16	16	17
Speed, submerged, knots	10¾		9–10	10	10
Armament, torpedo tubes	8		6*	4*	5*
Armament, guns	0		2	2	2

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* Doubtful.

Considering only boats in active commission and of tried qualities the submarine of to-day has about the following characteristics:

Surface displacement	650 to 750 tons
Submerged displacement	800 to 900 tons
Surface horsepower	1600 to 2300 tons
Surface speed	15 to 17 knots
Submerged speed	9–11 knots
Armament	2 guns of from 3 to 4 inches calibre and 4 to 8 torpedo tubes.

Experience in the Dardanelles, Baltic and North Seas has demonstrated the wide radius of action and efficiency, when operating submerged, of these boats.

The building of modern submarines of smaller surface displacements than 650 to 750 tons is due to military and financial needs and not to engineering limitations. During the last four years boats ranging from 35 to 1100 tons have been laid down.

Above 800 tons these are properly submarines of the future. The smaller ones of those remaining may be explained by certain military and cost considerations. For defensive purposes the only armament is the torpedo, and the main advantage is the submerged condition. Also there is advantage in increasing the number of units. Increasing displacement improves surface qualities more than submerged, or armament, and, because of greater cost, decreases the number of units available. Recent construction programs appear to confirm the opinion that the smallest types are suitable for coast and harbor defence. The characteristics of the *harbor-defence* type are as follows:

TABLE IV.

	Feet	Inches
Length	66	10
Surface displacement, tons	35	
Submerged displacement, tons	43	
Engines	Diesel	
Horsepower, surface	50	
Speed, surface, knots	8	
Speed, submerged, knots	6	
Radius, surface, knots	150	
Radius, submerged, knots	18	
Armament, torpedo tubes	2	

For *limited coast lines*, such as those of Denmark and Holland, larger units, such as the following designs, have been adopted:

TABLE V.

	Design 1 Feet	Design 2 Feet	Design 3 Feet
Length	98	119	116
Surface displacement, tons	132	165	187
Submerged displacement, tons	149	204	229
Horsepower, surface	300	450	350
Speed, surface, knots	11	12	11.5
Radius, surface, knots	1000	1000	750
Speed, submerged, knots	8.5	8	8.5
Corresponding radius, knots	25	24	25
Armament, torpedo tubes	2	2	3

Where there are *long coast lines* or scattered possessions, and financial considerations are not too pressing, vessels of surface displacement of from 350 to 550 tons are now used. The characteristics of some of the best known are as follows:

TABLE VI.

	U. S. K Class	English D Class	French Pluviose	German Brumaire
Length, feet	153	150		
Surface displacement, tons	389	550	400	400
Submerged displacement, tons	519	615	550	550
Engines	Diesel	Diesel	Steam	Diesel
Horsepower, surface	900	1200		850
Speed, surface	14	14	12.3	13
Speed, submerged	10.5	8–9(?)	8	9
Armament, torpedo tubes (internal)	4	3	1	1
Exterior launching apparatus			6	6

The *offensive submarine* is exemplified in its highest development by boats of 650 to 750 tons surface displacement, whose characteristics are given in Table III.

Spear[12] feels that the *harbor-defence* type will not be perpetuated, but the *coast-defence* and *offensive* types will be built in large and increasing numbers. He outlines the military factors affecting future development, and reasons out that the limiting conditions will be:

Submerged speed not less than 10 to 12 knots.
Torpedo tubes not less than four.
Time required to submerge not more than three minutes.

These can all be obtained to-day with a good design of about 250 tons surface displacement. With this list as the minimum the additional factors should be: Submerged radius at least 100 miles at five knots, which will not raise minimum displacement above 250 tons, and will permit of surface speed of 11 to 12 knots and a radius of 1000 miles.

The influence of the engine is shown by an example from actual practice where, with a surface displacement of 350 tons, a trial speed of 14½ knots was obtained with a light two-cycle engine (weighing 56 pounds per horsepower) of 450 horsepower at 450 revolutions. Replacement with heavier engines (86 pounds per horsepower) operating at 375 revolutions per minute reduced the speed to 13 knots.

At present the largest defence boats ordered by the United States are 500 tons surface displacement and 14 knots. Seakeeping qualities place the minimum surface displacement at about 350 tons. A large number of submarines of this size have successfully crossed the Atlantic under their own power.

Spear gives the characteristics of three possible types of boats fulfilling the condition of a 2500-mile effective cruising radius at 11 knots.

Laubeuf[13] (1914) outlines the general tendency of the development of submarines, illustrating with specific boats. He points out that offensive power increases at only a fraction of the rate of increase of tonnage. He believes future development will be in two directions: toward (1) a boat of moderate displacement (400 tons), easy to handle, well armed, and with a small radius of action for coast defence, and (2) fleet submarines of, say, 1200 tons and 22 to 23 knots on the surface, 15 knots submerged, powerfully armed, and with a wide radius of action.

The article is of interest because of the author's illustration of his points by mention of actual boats in service.

Nimitz[14] (1912) considers the facilities of the submarine in respect to communication, mobility, invulnerability, and offensive strength, and the military importance of each.

Besides all usual visual methods, present practice gives a wireless radius up to 50 miles. This could be increased with high masts. For submerged communication, bells are used, and signals have been sent, under the best conditions, eight miles and, under the worst, one-half mile. No reliable radio method has yet been devised. The invulnerability depends wholly upon invisibility. The offensive strength lies in the ability to fire from near at hand before detection.

The submersible and submarine are compared as to advantages and disadvantages. Possibilities of tactics and military methods are described.

Reference[15] (1916) gives a summary of the performance of submarines during the war up to October, 1916, pointing out their failure to come up to expectations, either in combating larger battleships or in preventing transport of troops to France. The Imperial German Chancellor, in speaking before the Federal Council on August 9, 1916, stated that without sinking at sight submarines could not maintain blockade, and also, that Germany could not build submarines rapidly enough to make up her losses. The article gives 19 as the number of submarines known, more or less definitely, to have been sunk in 1915. The article concludes that, while the submarine has much to its credit, it cannot and is not meant to compete with the surface ship.

Bernay[16] (1912), in discussing French boats, states that the submarine devotes from 35 to 45 per cent. of its displacement to propelling machinery and 20 to 30 per cent. of the displacement to the submerged propulsive machinery. The low submerged speed is, tactically, the weakest point in the submarine. It has been increased from 6 to 7 knots to 10 or 12 in the latest types by improvements in the storage batteries, which seem, however, to have about reached their limit. This increase in speed has necessitated a more substantial periscope standard, in order to avoid excessive vibration, and this makes it more easily seen. Submerged equilibrium, trim, etc., are more difficult to maintain.

The surface speed has been increased with the same tonnage (400) from 12.5 knots in 1905 on the *Pluviose* with steam engines to 15 knots in 1912 on the *Faraday* with oil engines.

The *Gustave-Zede* (1910) and *Nereide* (1911) reached 740 tons surface displacement, an increase demanded for increased speed. England built in 1912 an 800-ton boat simply to get 16 knots, and the Germans are doing likewise.

Lecointe[17] (1911) considers the advantages of the design of submarine designated as the system "del Proposto" and characterized by the use of compressed air instead of storage batteries for submerged propulsion. The air is stored under high pressure. Submerged it operates, first a compressed-air motor, which may be the compressor reversed, if need be, and after expansion is drawn into an interior combustion engine. A part may be used for ventilation.

The system uses a Diesel engine, as most efficient both in fuel and air consumption. The weight of the compression flasks is reduced by use of high-grade material, such as nickel steel, and by winding with wire, to 4 kilogrammes per kilogramme of air. It is claimed that the weight of air containers per E. P. H. hour is between 16 and 24 kilogrammes, or one-third to one-half that of a very light storage battery. The weight of the latter per horsepower-hour on the propeller is given as about 40 to 50 kilogrammes. The volume per E. P. H. is given as 66 dm^3 to 80 dm^3. The volume of the air containers for a pressure of 250 kilogrammes is not more than 18 to 20 dm^3 per E. P. H. hour.

In approaching an enemy the Diesel engine would be cut out and the boat run by compressed air exhausting into the boat, thus avoiding all gas escape. Considerable distances could be transversed at three to four knots before the pressure rose above three atmospheres.

The inventor claims the boat would be much improved in ventilation, buoyancy, speed of submerging, safety of navigation, etc. Laurenti has worked out the details of design of such a submarine, and gives the weights of the various parts. He gives the radius on the surface as 1450 miles at 16.5 knots, and, submerged, 27.6 miles at 14.60 (maximum 16.6) knots, or 39 miles (*milles*) at 10.3 knots. Without escape of gas the latter would be 18.7 miles at 3.6 knots.

The author claims that a boat of 1000 tons displacement, with a combined battery of compressed-air tanks and Diesel motors weighing 17 kilogrammes per E. H. P., would have the following characteristics:

Maximum surface speed.....................	20	knots
Maximum submerged speed	23.2	knots
Radius of action, submerged, at maximum speed	34	miles

It is stated that the German marine has acquired rights (March, 1911) to the invention.

Apparently no experimental trials had been made. Considerable more detail is given in the original.

Reference [18] (1911) gives practically the same material as [17] in a slightly different form.

Daubin [19] (1916) discusses the possible functions of a large, swift submarine, capable of acting in concert with a fleet. The present-day foreign boat of 800 tons, with a surface speed of 15 to 17 knots and the ability to remain at sea for three weeks, is fairly efficient as a commerce destroyer, a guerilla of the sea, or for second-line defence. But geological and military reasons would prevent such boats from being of great value to the United States. Daubin believes that a large, high-speed boat, 18 to 20 knots, with a submerged speed of at least 14 knots and a submerged radius of 30 hours at lower speed, equipped with long-range torpedoes in broadside tubes, and with guns, would offer very great advantages and should be at least attempted. He considers that there is only one quality in which it would be experimental, and that is the speed. He believes such boats could be built in 14 to 20 months, if rushed, and answers the various objections which have been advanced. He believes steam propulsion will be necessary.

Klein [20] (1912) classifies submarines as single and double hull. The first is the original type exemplified by the Holland boat, and used for all the English and Japanese, and almost all of the American boats. The second type is exemplified by the Laubeuf, Krupp, Laurenti, and Lake boats. All German and the greater number of French and Italian submarines are built on it.

Klein [20] compares the two types, mathematically, in regard to (1) stability, (2) seaworthiness, (3) diving qualities, (4) water resistance, (5) resistance to collision.

His conclusions are as follows:

1. The metacentric height in the diving position is better for the single hull. In the swimming position it is too small for the single hull and too great for the double-hull boat. It has been proved that the double-hull boat must have a very great reserve displacement and an excessively great metacentric height in the swimming state in order to get a serviceable metacentric height in the diving condition. This chief objection to the double-hull

boat has been considerably lessened in boats carrying liquid fuel by doing away with the "indifferent" water ballast.

2. The behavior is alike in regard to freeboard, distribution of weight, and reserve displacement. Because of greater reserve displacement the seaworthiness of the double-hull boat is considerably better. Yet it is impossible to get as large a reserve displacement with the single hull.

3. The single hull has an advantage in filling and emptying the ballast tanks. In regard to "dynamic" diving and diving on a level keel, the action of both is similar. For the dynamic method while under water the conditions are equally favorable.

4. In the swimming condition the two-hull boat, and in the diving the single-hull boat, has poorer resistance. Recently the single-hull boats have been built in a form similar to the torpedo boat, and therefore, now, with similar limitation of other characteristics, as good resistance conditions in the swimming condition can be obtained with the two-hull boat.

5. The two-hull boat is better protected against slight collisions. The author's and the Laurenti type of boats has special protection against deck collision. For heavy collisions the only protection is water-tight compartments, and the possibilities for subdivision are the same for both.

American Boats.—Reference [21] (1917) states that the largest American submarine afloat to-day is not over 16 knots, total brake horsepower 1200, while in 1913 Italy accepted four of 18 knots surface and 14 knots submerged speed, total brake horsepower 1500 each. Vickers has built for England nearly 100 submarines of the E-class, and is building 17 more. This class has a speed of 17 to 18 knots.

Reference [22] (1917) states that probably the largest submarine ever built in the United States has completed her trials. The Fore River Shipbuilding Company built her under contract for the Electric Boat Company for the Spanish Government. Her surface speed is 15.36 knots, 1.36 knots better than any American submarine in commission. She is 196 feet long, with a beam of 18¼ feet, a displacement of 700 tons, and a complement of 24 officers and crew. Her cruising radius is 8000 miles. Her engines are the Nlesco.

Bids [23] (1917) has been received by the Navy Department for 34 seagoing submarines of the 800-ton type. The Electric

Boat Company proposed to build 18 within 16 to 26 months at $1,524,000 on the Atlantic or $1,592,000 on the Pacific coast, each. The California Shipbuilding Company and the Lake Torpedo Boat Company would build from four to eight boats each in 24 to 32 months at prices from $1,288,000 to $1,299,000.

Reference [24] (1913) describes briefly a submarine built by the L. A. Submarine Boat Company, Long Beach, Calif., after designs by J. M. Cage, using gasoline engines for both surface and submerged propulsion and with propellers at the bow. The engines are two 90-horsepower, running 900 r.p.m. at full speed, and the boat has an estimated surface speed of 19 knots. It carries compressed air enough to run the engines at full speed for four hours.

Reference [25] (1912) gives the dimensions of the United States submarines E-1 and E-2, launched in 1911 by the Electric Boat Company, New London, Conn. These are:

Length	135 feet 3 inches
Breadth	14 feet 11⅝ inches
Draft cruising	12 feet
Surface displacement	284 tons
Submerged displacement	367 tons
Armament, torpedo tubes	4

A number of photographs are shown.

It is stated [26] (1916) that the United States naval program includes an appropriation of $250,000 for a submarine equipped with the Neff system of propulsion, which eliminates the storage batteries and uses the same source of power for both surface and submerged cruising. The propellers are located at the bow. Large quantities of air for ventilation and combustion are carried in high-pressure air flasks.

The Neff system is the product of the L. A. Submarine Boat Company, Long Beach, Calif., and worked very satisfactorily in 1913 on a 75-foot model.

German Boats.—Treitel [27] (1916) gives the principal characteristics of German submarines under construction as follows:

Displacement submerged	5000 tons
Length	126 metres
Power, surface	18,000 horsepower
Speed, surface	26 knots
Cruising radius	18,000 to 20,000 miles
Speed, submerged	16 knots

Armament:	
Torpedo tubes	30
Total torpedoes	90
Mines	125 to 150
Guns, of medium calibre.	
Guns of small, on anti-aircraft mounts.	
Reënterable turrents and conning tower.	

These dimensions, etc., would call for a displacement of 2500 tons and a storage for 600 tons of oil.

The latest German boats which have had their trials have the following characteristics:

Displacement	2400 tons
Length (over all)	85 metres
Beam	8 metres
Height, excluding conning tower	6 metres
Speed, surface	22 knots
Power, surface	7000 horsepower
Speed, submerged	14 knots
Cruising radius	6500 miles
Armament:	
Torpedo tubes	8 to 10
Guns, small and medium	4 to 8
Supplies for six weeks.	
Crew, 50 to 60.	

Laubeuf [28] (1915) discusses the German submarine and the rôle it has played in this war. He states that, as well as is known, the Germans had, in 1914, 24 submarines in service and 14 under construction, of which last eight have probably been completed since. She also seized six other boats under construction for foreign navies, making her total 38, of which the oldest was launched in 1905. A table is given, showing the characteristics of these boats.

In 1907, when France had 85 submarines, Germany had none. She profited by the extended experience and experimentation of France before beginning construction. Her building plan would have given her 72 boats by 1917. Austria had, at the outbreak of war, six submarines in service and four under construction.

Laubeuf discusses the military functions of the submarine. They have been successful in preventing bombardment of ports and in forcing the blockading fleet to remain at a long distance. He gives a list of their victims.

The German submarines have all been built by private concerns, the French by the state. The typical construction of the German submarine is briefly described.

Reference[29] (1916) states that the building of the *Deutschland* consumed about five months, the Krupp plant having equipment capable of turning out one vessel of this type each month. The *Deutschland* is 313 feet long, 30-foot beam, with a displacement of about 2000 tons. She requires 32 feet for complete submersion. She can carry 650 tons of cargo. The details of engine construction are contradicted by Palmer,[65] and so are not copied here. Her speed is said to have been as high, at times, as 14 knots on the surface. Only 85 tons of fuel were used on the 16-day voyage to America, leaving enough oil for the return trip.

She was said to be equipped with two microphones for the detection of the approach of other vessels.

A general account of the *Deutschland's* trip is given.

The *Deutschland* covered a total of 4100 miles in 16 days. Other long submarine voyages have been those of the German U-51 in 1915, 3,282 miles from Wilhelmshaven, Germany, to the Dardanelles in 42 days; 14 Canadian-built, American-designed boats in 1915, from Quebec to Plymouth, under escort; 4 K-type American boats in 1915, 2100 miles from Seattle to Honolulu in 11 days; English E-14, from Devonport to the Dardanelles; English E-14, 46 days to the Mediterranean.

Austrian Boats.—Reference[30] (1917) says that at the outbreak of the war the Austrian submarine navy consisted of only six boats, all launched in 1908–09. Six others were under construction, some of which afterward succeeded in reaching the Adriatic. The boats had the following characteristics:

No.	Type	Built	Time to Submerge	Submerged displacement	Speed surface	Knots submerged
2	Lake	Pola Arsenal	2¼ minutes	270 tons	12	7.3
2		Germania Yard, Kiel	15 seconds			
2	Holland	Whitehead Works, Fiume		270 tons		
6		Germania Yard, Kiel		1000 tons	18	

Some German boats were shipped by rail, of which one, a mine layer, was raised after having been sunk, and restored by the Italians. She was evidently hastily built, of crude construction, small size and low speed, and carried no armament beyond a dismountable machine gun.

Reference[31] (1914) describes the recent addition to the Austro-Hungarian Navy of the U-III and the U-IV, built at Germania Yard, Kiel, by Krupp. They are 142 feet long, 12 feet 4 inches beam, and have a surface displacement of 235 tons. The general construction is described.

Surface propulsion is by means of two two-cycle heavy oil engines with a total of 600 horsepower. Submerged the boat uses two electric motors designed to develop 320 horsepower. The surface speed is 12 knots, and submerged 8.6 knots. At 10 knots the radius is 1200 miles on the surface or 60 miles submerged, the latter at six knots. The boat can be brought to the surface in one and one-half minutes. The armament consists of two eight-inch Whitehead torpedo tubes.

British Boats.—Reference[32] (1917) copies from the *New York Sun* the report of the recent successful trial of a 21-knot, 5000-i.h.p., steam turbine-driven British submarine.

Reference[33] (1913) describes the English submarine navy, which is stated to be larger than any other. Each type is briefly described and the history of the boats included in it given.

French Boats.—Reference[34] (1911) describes the manœuvres of the French flotilla in 1909–10, and gives the conclusions reached as to the qualities of each of the types of boats engaged.

Reference[35] (1914) states that there were in France, under construction and projected for 1914, 25 submarines, as follows:

No.	Type	Surface displacement	Length meters	Beam meters	Depth meters	Speed knots	Engine
10	*Chlorinde*	410	54	5.1	3.3	15	Diesel
2	*Zede*	797	74	6.0	3.7	20	Diesel
3	Qu-102	520	60.6	5.4	3.7	17	Diesel
8	Qu-105	833	75.	6.4	3.99	19	Steam
2	Qu-107	630	68	5.5	3.75	17	Diesel

Dutch Boats.—Reference[36] (1914) describes with detailed drawings the construction of a Dutch submarine. She is 48.58 metres over all, 4.32 metres beam, and has a surface displacement of 328.8 tons. She has two eight-cylinder, double-acting, reversible Diesel engines of 850 i.h.p. at 450 r.p.m., of the Augsburg type, giving a maximum speed of 16 knots for three hours and a cruising speed of 11 knots.

For submerged running the storage batteries of 3830 ampère-hours for 5 hours, or 4400 ampère-hours for 10 hours, will give

11 knots maximum cruising speed for one hour, or eight knots for four hours.

A submarine bell and receiving instrument are installed. The armament consists of two torpedo tubes at the bow and one at the stern for 45-cm. Whitehead torpedoes. There are two periscopes.

Engineering[37] (1912) describes briefly the tests of a submersible recently completed on the plans of Whitehead & Co., Fiume, by Koninklyke Maatschappy "de Schelde," at Flushing, for the Dutch Navy. The following special points are mentioned: Pumps capable of pumping against a head of 200 feet; a static driving gear by means of which, and at small expense of power, an exact regulation (within 1 dcm.) of the desired depth is possible; two periscopes 6 metres long; turning diameters of 180 metres on the surface and 160 metres submerged; extreme habitability, with accommodations for 11 men for one week. The boat is 105 feet long, with 10-foot beam. Her 300-horsepower Diesel engine and electric motor give her a surface speed of 11.2 knots and a maximum submerged speed of 11 knots. Her radius of action on the surface is 1000 miles at 10 knots, and submerged 6 hours 23 minutes at seven knots, or 1 hour at 11 knots.

Miscellaneous Boats.—Reference[38] (1909) is an unsigned article describing the development and present status of the submarines of the different navies. The policy and progress of experimentation in the various countries is outlined and the results critically examined. A list is given of the submarines in commission, building, and projected, with the type, year of building, motive power, horsepower, displacement, dimensions, velocity, radius, and torpedo tubes of each.

Weaver[39] (1911) describes in great detail the cruise of the submarine *Salmon* from Quincy, Mass., to Bermuda and back in 1910.

The *Salmon,* like practically all United States submarines in service, was of the modified spindle form instead of the ship form of the Lake, Laurenti, Laubeuf, and Krupp type. The cruise demonstrated that this single-hull type has, (1) for a given power of machinery, a higher submerged velocity, and (2) higher structural strength for diving in deep water. These advantages are gained at the cost of habitability and seaworthiness.

The *Salmon* was 40.097 metres long over all, 4.232 metres beam, total displacement submerged of 337 tons, and was equipped with gasoline engines. She carried 22 persons. The full log is given and shows the behavior of the submarine in heavy weather. It was concluded that in storm a submarine is safer than any other type of boat, but it is very uncomfortable in heavy weather.

Reference [40] (1916) gives photographs and a brief description of the German mine-laying submarine C-5, which was 110 feet long and 10 feet maximum diameter. She carried 17 men and one officer, was driven by two-cylinder Diesel engines, and had a surface speed of about six knots.

Bieg [41] (1915) suggests the possibility that an offensive submarine might be very serviceable in combating the operations of a fleet against our shores, and outlines the characteristics of a type which he would like to see tried out.

His boat is a heavily armored ship with hull designed for the greatest efficiency for surface running. She would not dive, and would submerge only to the awash condition, and merely to make herself invisible while out of range. Within range she would depend upon her armor, and the illusiveness of so low a target as well as fighting within a range so short that it would be hard to reach with the big guns.

Musoforiti [42] (1917) has invented a device for automatically raising a sunken submarine by inflation of collapsed, air-tight bags with acetylene generated by the action of water on calcium carbide.

Skerrett [43] (1912) describes a combined salvage and testing dock for submarines, launched by the Italian Government.

Reference [44] (1911) describes a French submarine salvage boat, giving the dimensions. She is without motive power.

Reference [45] (1914) describes the Italian submarine salvage vessel *Anteo,* which is designed to follow the fleet during manœuvres or in time of war. She is propelled by two compound engines of 800 horsepower. She is 165 feet long and 78 feet broad, and has equipment for raising 400 tons from a depth of over 200 feet at a rate of over four feet per minute.

Reference [46] (1912) describes the submarine transporting ship *Kanguroo.* This boat is so designed that a part of the bow may be removed and the submarine floated directly into the hold, which is 193 feet long.

Dantin[47] (1916) describes the Brazilian submarine depot motorship *Ceara*. This ship has facilities for lifting and dry-docking the submarines attached to it, as well as accommodations for their crews, supplies, etc. She is 328 feet long, 51 feet broad, with a displacement of 4130 tons and a speed of 14 knots. Her equipment is described very fully. Particular attention is paid to her Diesel engines.

Davis[48] (1916) gives very fully the constructional details and general layout and equipment of the United States submarine tender *Bushnell*, with tables of dimensions and diagrams.

References[49] (1914–15) give in detail the dimensions, equipment, and tests of the submarine tender *Fulton*. The second of the references is the more detailed, but does not cover the trial tests.

Motorship[50] (1917) gives much detail and discussion of submarine chasers and patrol boats, and of the Diesel engines used in them. Builders are given.

Lake[5] (1915–16) discusses the advantages and practicability of a special type of submarine for navigation under ice, as in polar exploration. He also suggests its use in locating and gathering shellfish from the bottom of the ocean. He has already designed a special type for the purpose.

Dietze[51] (1911) deals mathematically at some length with the physics and hydraulics of the submarine, methods of diving, and changes in buoyancy.

Klein[52] (1913) gives a mathematical investigation of the principles of dynamics underlying the operation of submarines, under the headings of "Equilibrium Conditions," "Stability," "Determination of the Magnitude, Direction, and Position of Water Resistance by Means of Models."

He gives a bibliography of technical articles on the submarine from 1859 to 1911, which he states is as complete as possible.

Werner[53] (1914) discusses the stability of submarines while filling the ballast tanks, and deduces mathematically the conditions that must be fulfilled for safety, and their translation into proper design of boat.

Reference[54] (1916) describes the deep submergence test, at 200 feet depth, of the Lake type boat G-3. The pressure at this depth is 88 pounds per square inch, and the boat was subjected to it for 14 minutes.

II. PROPULSION.

Engines.—Berling[55] (1916) describes in considerable detail the general equipment used for propulsion in submarines. He gives the combined weight per horsepower of all the propulsive machinery of a submarine as about eleven times that for the modern torpedo boat. On account of the greater pressures the hull of the former must have 20 per cent. greater weight, and of the total building weight only 28 to 30 per cent. can be allowed for machinery, compared with 48 to 50 per cent. for the latter. These facts explain the limited speed of the submarine.

The Diesel engines consume about 190 to 220 grammes (0.42 to 0.485 pound of fuel per horsepower hour.

Berling shows mathematically that any increase in the weight of surface propulsion machinery must cause a decrease in submerged speed, and *vice versa.* By a comparative table, computed from data of tank-model towing experiments, propulsive coefficient measurements, and British Admiralty formulæ, he proves that the oil-electric boat of moderate size has reached the upper limit of propulsive effect.

Steam was early used for surface propulsion, but maintenance of bearable temperatures within the submarine demands, with it, the use of extensive cooling and ventilating apparatus. The steam engine, besides occupying more space, also consumes about 3.5 times as much oil per horsepower as the Diesel engine, and so makes it impossible to obtain more than 15 knots surface speed without reducing the radius of action considerably, a tendency which is increased by the crowding of the living spaces.

Berling describes very fully the operation of the steam soda-boiler power plant of the German inventor Hönigmann, with illustrations and arrangement of a proposed submarine of 700 tons fitted with the system.

With this system, surface cruising is done with a steam engine. At the same time part of the steam is used to concentrate a sodium hydroxide solution. When submerged, low-pressure steam heats this solution and is absorbed by it. The latent heats of condensation and of solution of the sodium hydroxide produce enough further heat to generate steam in a flask surrounding the soda container for running the engines.

No exact details of such engines have reached the public since 1885, but the author gives what he regards as probable figures.

Evaporation of the sodium hydroxide takes one and one-half hours when the boat is at rest and three to four when under way, compared with a minimum of six to ten hours for charging storage batteries. The oil consumption is about 2.8 times as much per horsepower as with the oil-electric drive. A 3000-horsepower soda boiler capacity should take about three tons of oil for renewal and then be capable of from one and one-quarter to one and one-half hours at 12½ knots submerged. The weight for the submerged installation is very much lower than for any other type. The life of the soda boiler is rather limited and the space requirements are high. A table of computed weight of machinery, speed, radius, etc., for each of eight different displacements is given.

(See also Berggeen,[63] ii, p. 286.)

Berling also outlines the "Del Proposto" system, using either compressed air or oxygen to supply the internal-combustion engines during submerged cruising. He states that one pound of fuel oil requires about 24 pounds of air for combustion. He illustrates the arrangement by diagram. The machinery parts are designed so light as to allow very little factor of safety. The result is a boat of only 435 tons displacement, capable of 1400 sea miles awash at 16.45 knots and 27.6 miles submerged at 16.6 knots. (See Lecointe[17] (1911), i, p. 96, and Berggeen[63] (1916), ii, p. 264.)

Berling considers what he calls a rational boat construction of sufficient armament, convenient living spaces, diving rudders, etc., and analyzes, the results from the installation of the above-mentioned different types of machinery. He tabulates the weight and space occupied by each type of installation, and the capacity, speed, and radius of the resulting boat. He gives comments and data of actual tests on the combinations listed. He shows by curves (1) weight requirements for submerged machinery installation with increasing capacity, (2) space requirements for submerged machinery installation with increasing capacity, (3) resistance curves for submarine and for submersible, on surface and submerged.

Berling concludes with the statement that the capacity limit of submarines will always be low so long as two fundamentally different types of machinery must be used for propulsion. Past failures have been due, first to the weight of the hull, and second, to the fact that, with single motors for both surface and submerged running, the oxygen, which must be carried in flasks, very considerably increases the weight and space requirements.

The article gives a good idea of how closely balanced and interrelated are the requirements and limitations of space and machinery, weight and speed.

Reference[56] (1916) is the original of [16] and is illustrated with many photographs as well as diagrams. The former are omitted from the translation.

Hoar[57] (1916) considers that the present-day submarine dates from the adoption of the internal-combustion engine as a source of power. There is a tendency, however, at the present time to return to steam.

The gasoline engine was first used and was installed in the A, B, C, D, and three of the G class of our navy. It gave very satisfactory operation, and, in view of its recent perfection, could now be expected to do even better. It was light, compact, and simple. The drawbacks are cost of fuel, danger of fire, explosion, and asphyxiation or poisoning by the escape of carbon dioxide or monoxide gas. Of these the author considers only the first real and insurmountable.

The Diesel engine, which was next adopted, burns almost any low-grade oil which can be vaporized, and it develops 1 brake horsepower per hour from 0.55 to 0.63 pound of fuel. The theory of its operation is simple and is given in brief for both the two-cycle and four-cycle types. The economy of the former is much lower than the latter.

In practice the engine is far from simple, as the excessive temperatures, going as high as 3000° F., together with the high cylinder pressure (500 to 900 pounds per square inch), impose demands hard to meet.

The ideal submarine engine should be of high power and speed, light, simple, and accessible. Reliability and accessibility have to be sacrificed at present in order to make the Diesel engine meet the other requirements, and simplicity is little likely ever to be attained with it. The engines in service give a great deal of trouble, and the author believes that the relative success of the German boats in this war has been due to their working in relays and being given a thorough overhauling after each cruise.

The recent increase in size of submarine, demanding an increase in engine power which the Diesel cannot meet, together with the weight and space limitations, and the increased efficiency and reliability of the steam engine, have led to a certain reversion to the latter.

It is now possible with the oil-burning boiler to get an efficiency as high as 0.7 to 0.8 pound of fuel per brake horsepower. The weight is much less and the simplicity and accessibility much greater than for the Diesel motor. The mean effective pressure in the steam unit is higher, and the maximum cylinder pressure is about one-quarter that in the Diesel engine. The extreme temperature is less than a fourth.

The ideal propulsion would be a single power plant for surface and submerged running. Hoar mentions the "Del Proposto" and soda-boiler schemes. He accredits the last to D'Equevilley, a Spanish engineer, but states that the principle is old, having been used in this country by Luck in 1873. The system has also been tried in Germany and France, etc., but it is not believed that any great success has been attained.

The L. A. Submarine Boat Company, of California, with which Hoar is connected, has recently perfected a system using the same unit for surface and submerged propulsion, but details are not yet available for publication. This is mentioned in reference [19] (see part I).

Bernay [16] (1912) states that a French submarine built in 1902, designed to operate submerged on oil engines supplied by compressed air, was a failure. Two others designed to operate in closed cycle with oxygen were never finished. He states that an Italian firm is actually building a boat on the "Del Proposto" system.

Chalkley [58] (1915) mentions the fact that the submarine in its present form owes its existence to the internal-combustion engine. Gasoline was used at first, and several such engines are still doing good service.

The first Diesel submarine engine was completed in 1907 or 1908, and this engine was adopted practically at the same time by British, French, and German navies. Difficulty was encountered from the first in the necessity for increasing the speed of rotation in order to get a minimum weight of machinery. The high temperature of combustion, 1200 to 1500° C., led to further difficulties.

The weight of the slow-running Diesel engine used on mercantile vessels is about 350 pounds per brake horsepower, against 50 to 70 pounds for the submarine engine.

The author discusses the types of engines, two-cycle, four-cycle, etc., used by the different navies, and gives descriptions of the manner of operation and illustrations of the Krupp, Nürnberg, Sulzer, and Polar.

He concludes by pointing out that the development of the submarine is limited only by the peculiarities of the engine. Much larger and faster (20 knots or more) boats will be built just as soon as satisfactory motors of 2000 or 3000 brake horsepower are produced.

The internal-combustion engine is ideal for the submarine, in that it can be started or stopped instantly, permitting rapid submergence and emergence.

Lake[5] outlines the transition from one type of gasoline engine to another, and finally to the Diesel engine, and the troubles encountered. He believes that the demand for increased speed in the last years has come so rapidly that reliability has been sacrificed. Bearing pressures have been run up to 1700 pounds per square inch, and complication of construction has increased tremendously. He was present at a test of a reversible, continental engine running at 450 revolutions per minute on a small boat, and the noise was such that conversation without shouting was only possible on deck near the bow. A photograph is given.

This engine works very well at 100 revolutions per minute, but when run up to the 350 to 400 revolutions per minute necessary to get the required horsepower into the limited space available in a submarine the noise is terrific.

The Diesel engine of 500 pounds or more per horsepower works satisfactorily on land, but the attempt to change to a reversible high-speed engine of 50 pounds per horsepower has brought great trouble. Millions have been expended without yet producing a satisfactory result.

"There are some destructive actions in connection with large, high-speed, light-weight internal-combustion engines that practically all designing engineers have failed to grasp. Otherwise engineers of all nationalities would not have failed to the extent they have, and I do not believe there is a submarine engine in service to-day that has fully met the expectations of its designers and builders. It is unfortunate for the engineering profession that government policy will not permit of a full disclosure of the defects of engines and other equipment in government-owned vessels. Were a frank disclosure made other inventors and engineers would, in all probability, take up the problems, and they might then sooner be solved."

Lake concludes from his experience that, in the successful heavy oil engine which will eventually be produced, bearing pressures should not exceed 1000 pounds per square inch of projected area on main bearings or crank-pins. For some as yet undiscovered reason, the diameters of crank-shafts must be increased from the five-inch, which are more than ample to transmit 600 horsepower at 400 revolutions per minute on the steam engine, to at least seven inches for the same service on the Diesel submarine engine. Lake gives specific instances where disregard of this point has brought failure in operation. He states that the recognition by our government of the need for greater reliability is shown by the fact that the latest requirements eliminate the reversible engine, so that reversing, even on the surface, must be done on the electric motors. While this is a step backward, it will give the engine builders a very necessary chance to catch up.

Photographs are given of the latest model of the Krupp six-cylinder, two-cycle engine, of which a large number were under construction just before the war; of the Fiat-San Giorgo six-cylinder, two-cycle engine, designed for 1300 brake horsepower at 350 revolutions per minute, which is the largest submarine engine yet built of which Lake has any knowledge; of the Augsburg four-cylinder, four-cycle engine, which is used and has given good service on a number of German submarines, in spite of its greater bulk and weight, because of its fuel economy and reliability; and of the Sulzer engine, used on some of the Lake and European boats. The last type is built in Switzerland and also by the Busch-Sulzer Brothers-Diesel Engine Company, at St. Louis, Mo., in "one of the most complete plants of the kind in the world."

The 1300-horsepower Fiat engine mentioned above as probably the largest submarine engine built to date had sucessful shop tests. Its subsequent history is not known. As the 25-knot submarines authorized by Congress (in 1914) must be at least 300 feet long and have not less than 10,000-horsepower to meet that speed requirement, the advance in engine development required is very considerable.

Bedell[1] (1917) states that the Nürnberg type of Diesel engine was the one chosen to succeed the gasoline engine for surface propulsion, and many are still in operation. The type has been much modified in recent American submarines, and the resulting engine has given good service. The heavy oil now used gives twice the number of horsepower-hours that can be obtained from the same volume of gasoline. Bedell gives no exact data.

The offensive (Spear[12]) (1915) or fleet submarine demands high surface speed, and this depends upon the surface power plant. The maximum power per unit of Diesel engine in actual service is about 1200 horsepower, but larger units are under construction.

Germany uses many four-cycle engines, but more commonly two-cycle, of very high speed and light weight.

England has almost wholly four-cycle engines of moderate speed and weight.

France and Russia use both types of greater weight and moderate speed. The tendency in the United States is toward a heavier engine of moderate speed, though a number of the fast, light-weight, two-cycle type have been installed.

The Diesel engines employed vary from 50 pounds per brake horsepower and 500 revolutions per minute to 100 pounds per brake horsepower and 350 revolutions per minute. A fair average is 70 pounds.

At present it is entirely practicable to install from 4000 to 5000 horsepower in a boat of 900 to 1100 tons surface displacement. With this displacement and a length of 260 feet the above power will give 20 or 21 knots. For 25 knots, if the length be restricted to 300 feet, excessive length being very undesirable, and with a displacement of 1200 tons on the surface, from 10,000 to 12,000 horsepower would be required.

Such a speed requirement may force the use of the steam engine, temporarily, in spite of its serious disadvantages, and with constant sacrifice of submerged qualities, all very serious defects from a military standpoint. France at present uses steam on a few of her submarines. Adaptation for the 25-knot submarine might easily prove a failure, and would be but a temporary expedient at best.

Discussion brought out several further points. The fact that the power plant for a 25-knot boat is a problem still unsolved was emphasized. High surface speed means sacrificed submerged speed, and *vice versa*.

The possibility of increasing the efficiency of the Diesel engine by increasing the oxygen content of the cylinder charge was discussed.

Lisle[59] (1917), in an article discussing in detail the "Submarine Diesel-Type Engines of the World's Navies," accredits Germany's successes in commerce destruction to her command of the Diesel engine. The various engines and their modes of operation are described with so great detail and so many illustrations, as well as numerical data, that full abstracting is not feasible.

Germany.—The majority of the German submarine engines have been built by Krupps and by the Augsburg Works of the Maschinenfabrik-Augsburg-Nürnberg. The Krupps had developed their two-cycle engine, with its special phosphor-bronze cylinders, crankcases, and cylinder heads, up to 900 to 1000 brake horsepower on a weight of 18 tons by the latter part of 1910, while in 1917 the largest Diesel engine in a completed American submarine is only 600 brake horsepower (1200 brake horsepower for a twin-screw boat). It is not improbable that the engines of the latest German submarines are 2000 brake horsepower each, or 4000 brake horsepower per boat, giving the larger boats of the U-class a speed of 20 to 31 knots. Of late the Krupps are devoting their attention to the four-cycle type, and are thus able to revert to cast-iron construction.

The first set of the Nürnberg two-cycle engines of 900 brake horsepower at 450 revolutions per minute was completed early in 1913, but was not so successful as the Krupp and Augsburg engines.

The Augsburg four-cycle engine is one of the most successful in the German Navy. It has a considerable overload capacity.

Germany has ordered engines from the F. I. A. T. Company.

Great Britain.—Submarine construction is wholly in the hands of Vickers, Ltd., and only of late has any information been available. The 1912 class were said to be 1200 tons, requiring two Diesel engines of about 1200 brake horsepower each. The latest engines give about 4000 brake horsepower per boat in 24 cylinders.

Reference[32] (1917) copies from the *New York Sun* the report of the recent successful trial of a 21-knot, 5000-indicated horsepower, steam turbine-driven British submarine.

Great Britain has also ten small submarines recently built by the Fore River Shipbuilding Company and engined by the New London Ship and Engine Company.

France.[59]—France first used gasoline power, then steam, later Diesel engines, then steam again, and now both steam and Diesel motors. She was the first to use the Diesel engine in submarines, and has had exceptional experience with many types. She has two submarines of about 5000 indicated horsepower in service. One (the Gustave Zede) is a 1000-ton steam turbine boat fitted with eight torpedo tubes. She is swift, but her cruising radius is only 2300 miles, or about half that of the modern Diesel-engined submarine.

The other is a Diesel-driven boat of 1700 tons, of a total indicated horsepower of 6000 or 4800 brake horsepower, which should give 20 knots. This is probably the highest-powered Diesel-driven submarine in the world, and should be the ideal fleet submarine sought by the United States.

Schneider & Co., who build these engines, give the following results of a series of tests made in 1914 on eight-cylinder reversible models:

TESTS OF SCHNEIDER-DIESEL ENGINES.

	Two-cycle	Four-cycle
Power developed	1121 b.h.p.	360 h.p.
R. P. M.	404.6	400
Fuel-oil per brake horsepower hour	240.7 gr. (9.2 oz.)	218.5 gr. (7.5 oz.)
Lubricating oil per effective horsepower hour	8 gr. (0.2 oz.)	8.8 gr. (0.3 oz.)

The Normand engines use tar oils, mineral oils, and vegetable oils.

The Sabathé engines employ combustion at constant volume and at constant pressure. The four-cycle type has a fuel consumption of 178 g. (6.10 oz.) of Russian residual oil per brake horsepower at the normal running speed of 400 revolutions per minute, a remarkably economical record.

France has also used Nürnberg, Krupp, Augsburg, and Sulzer Diesels.

Holland.—The design of the engines turned out by the Werkspoor Company is characterized by several radical departures from ordinary practice.

Japan.—Japan's submarines, so far as known, are installed with Schneider, Sulzer, Vickers, Krupp, Thornycroft, and F. I. A. T. engines, all of the Diesel type, except the eight Thornycroft sets supplied ten years ago, which are eight-cylinder, four-cycle, gasoline-kerosene motors, developing 350 brake horsepower on kerosene and 400 brake horsepower on gasoline, two engines to a boat.

The highest-powered foreign Diesel engines used are 16-cylinder Schneider sets of 1100 brake horsepower per engine. (See *Motorship*, December, 1916.)

Italy.—When the war broke out the F.I.A.T. Company had just completed a pair of engines of 1300 brake horsepower each for a Laurenti type of 700-ton boat. They must have given the boat 20 to 22 knots. These were intended for Germany.

Russia.—In 1913 designs were drawn for a very large seagoing submarine of 5400 tons displacement, 430 feet length, and 38 feet beam. She was to have two Nobel-Diesel engines, each of 9000 indicated horsepower, and a surface speed of 26 knots. Her armament was to be 30 torpedo tubes and five 14-cm. quick-firing guns. The author doubts whether her keel was ever laid. Russia has bought of M. A. N. and of Krupps.

United States.—The United States, largely because of lack of competition, has not reached the stage in the development of the submarine already attained by France, Germany, England, and Italy, four or five years ago. The largest boat under construction is the Schley, 1100 tons surface displacement (1500 tons submerged), to have four 100-brake horsepower Nlseco-Diesel engines giving a surface speed of 20 knots.

Shaw[60] (1917) describes a Danish submarine engine built by Burmeister and Wain and not mentioned in the article by Lisle. It is four-cycle, with six cylinders of 13-inch bore and stroke, and rated at 450 brake horsepower at 500 revolutions per minute. The length is 14 feet 6 inches and height 6 feet 2 inches. It weighs 19,800 pounds, or about 44 pounds per brake horsepower. Tests in competition with a slightly larger two-cycle German engine of the same power showed a fuel saving of 18 per cent. at full power and 24 per cent. at 10 knots.

[61] (1917) As an appendix to Lisle's paper [25] *Motorship* gives the following table:

SUBMARINE ENGINES OF THE WORLD AT A GLANCE.

Name	Country	Cycles	B.H.P.	Cylinders	Bore, inches	Stroke, inches	R. P. M.	Weight, tons	Weight per B.H.P.	Piston speed per minute, feet	Horsepower per cylinder
Augsburg	Germany	4	900	6	15.7	15.7	450	.....	.....	1177.5	150
Busch-Sulzer	U. S. A.	2	600	6	12.2	11.8	400	.....	.....	786.6	100
Craig	U. S. A.	4	300	6	12.5	15.0	300	.....	.....	750.0	50
F. I. A. T.	Italy	2	1300	6	.....	.....	400	25	43	......	217
Krupp	Germany	2	1000	6	13.7	15.7	425	18	40⅓	1112.1	166
Loire	France	4	420	6	.....	.....	400	.....	.....	.....	70
Nlseco	U. S. A.	4	600	8	.....	.....	450	.....	.....	.....	75
Nobel	Russia	4	180	6	8.8	11.8	500	2	30	983.3	30
Nobel	Russia	4	1200	6	.....	.....	400	.....	.....	.....	200
Normand	France	4	420	6	13.0	14.2	400	18.5	99	946.6	70
Nürnberg	Germany	2	900	8	12.0	13.3	450	.....	.....	997.5	112
Polar	Sweden	4	350	6	11.4	11.75	300	16.75	172	587.5	70
Sabathé	France	4	500	6	13.75	13.75	400	14.75	60	916.6	83
Sabathé	France	2	700	8	12.25	15.75	310	22.5	72	813.7	87
Sabathé	France	2	500	6	12.25	15.75	310	14.75	66	813.7	82
Schneider	France	2	2400	8	18.5	.....	.....	.....	.....	.....	300
Schneider	France	2	1100	8	13.0	14.5	400	.....	.....	966.6	138
Schneider	France	4	360	8	12.0	11.0	400	.....	.....	733.3	45
Southwark-Harris	U. S. A.	2	550	6	12.0	14.0	375	19.5	80	875.0	91
Sulzer	Switzerland	2	600	6	12.2	11.8	400	.....	.....	786.6	100
Vickers	England	4	1800	12	.....	.....	400	.....	.....	.....	150
Werkspoor	Holland	4	550	6	.....	.....	450	12	49	.....	91
Werkspoor	Holland	4	450	6	14.2	14.2	400	11	61	946.6	75
Werkspoor	Holland	4	240	..	.....	.....	450	4.5	42	.....	.....

Nimitz [62] (1916) describes in considerable detail the three types of submarine engines built by the Germans just before the war. Their principal characteristics are as follows:

Name	Weight per b. h. p.	Cycles	B. h. p.	at r. p. m	Cylinders	Cylinder bore	Stroke
Augsburg	51 lb.	4	1000	450	6	310-mm.	420-mm.
Nürnberg	46	2	850–1050	450	8	310-mm.	340-mm.
Krupp	45	2	900	450	6		

All are single acting. The Augsburg on full load consumes about 200 g. or 0.44 pound of fuel per brake horsepower. Augsburg and Krupp types are directly reversible by compressed air. The Krupp engine is built almost entirely of bronze, except for cast-iron cylinders and pistons and crank-shafts, connecting rods, wrist-pins, and valves of steel. The Nürnberg housing is of cast bronze, but the Augsburg engine is of iron and steel.

It is probable that the power of the Augsburg and Krupp engines has recently been increased by adding two more working cylinders. This would give the former at least 1350 brake horsepower on each shaft of a submarine. The Krupp engine power could be increased similarly, but its length would then be excessive. Nimitz gives considerable further detail as to the arrangement, etc., of these engines.

The modern submarine is usually driven by twin screws, and for surface propulsion depends on Diesel engines, one or more on each shaft. Germany's long experience with this type of engine has given her the lead in the construction of submarine engines, and upon this has rested her success in the submarine service.

A reliable engine is the heart of the submarine problem. Upon it rests the endurance of the crew and the whole success of the boat. No perfection of other details can compensate defects there. This surface motive power is also the weakest point in the submarine. Increase in size and tonnage and in the demand for higher speeds has complicated the matter further, and the last, particularly, has led to many failures of engines and hence of submarines. This factor has been at the root of the apparent failures of American submarines.

The endurance of the submarine is measured by four things: endurance of the main engines, fuel and lubricating oil supply, storage battery water supply, and endurance of the crew, of which the first and last come back to the reliability of the engine.

The engine is also the determining factor in the time necessary for building a submarine.

Berggeen[63] (1916) mentions briefly the soda boiler, accrediting it to d'Equevilley, a French engineer, and states that it is bulky and that its centre of gravity is high, but that the principle seems the best yet proposed. He also mentions briefly the characteristics of the Nürnberg, Fiat, Sulzer, and Polar-Diesel submarine engines.

Lisle[64] (1916) describes in detail the design of the Craig-Diesel four-cycle engine for submarines. This has been installed, so far, only in a modified form in two boats in which it was necessary to replace Vickers engines. Great claims are made for the type.

Palmer[65] (1916) discusses the type of Diesel motors installed on the *Deutschland*. H. Kleis, chief engineer of the boat, told the author, "The *Deutschland* is fitted with two six-cylinder, four-cycle Krupp motors developing 600 brake horsepower each at 380 revolutions." They are smaller than the regular Krupp submarine engine, which develops from 1200 to 1500 brake horsepower per unit at 500 revolutions. The motors are of steel and iron instead of the special Krupp bronze construction. Steel is used in the cylinder head and crank-case, and the cylinders are, as usual, of cast iron, with removable linings of the same metal. Krupp has retained bronze construction in the two-cycle motor, but no longer uses it in the four-cycle. The *Deutschland's* engines performed admirably, with absolutely no cracked pistons nor cylinder trouble. The longest non-stop run was 245 hours, and on the first round trip the engines turned over 11,000,000 times. Kleis gave further cylinder and stroke dimensions, but these are doubted by Palmer as inconsistent with the accredited horsepower, etc.

J. L. Bogert, in commenting on Palmer's article, states that the standard German submarine is believed to be 800 tons displacement (the *Deutschland* is not less than 2000, according to the cargo she carries) and capable of 17 knots an hour under the "full power impulse of her Krupp 850-brake horsepower, twin six-cylinder Diesel engines." From this he deduces the probable cylinder dimensions of the *Deutschland*.

Wentworth[66] (1916) presents for criticism and as a basis for further work the design (in 14 plates) of a light, reliable engine suitable for submarines, giving data and substantiating reasons for the special points involved. His engine, for which full data and drawings are given, is four-cycle, which he regards as superior because of the greater variability in speed possible, greater simplicity, and at least one-tenth higher efficiency. It fulfils the following conditions:

	Feet	Inches
B. H. P. per engine	450	
Revolutions	450	
Length over all not to exceed	14	9
Width not to exceed	3	8
Height above centre of shaft not to exceed	6	0
Distance below		23
Weight not to exceed	26,000 lb.	

The specific points of the design and the factors affecting each are discussed in detail, with particular reference to reversing, fuel and fuel feed, starting, compression, cylinder temperature, speed variation, fuels. Comparisons with ordinary practice are given.

Robinson[11] (1915) outlines the principle of operation of the Diesel engine, quoting from Milton (*British Institute of Naval Architects*, April, 1914).

Storage Batteries.—Berling[55] (1916) states that the modern lead storage battery has a life of about 400 charges, which means for the average submarine, making practice runs, a life of from five to six years. The most recent, with a 3½-hour discharge rate, weigh about 35.5 kg. (78.3 pounds) per horsepower hour delivered. The electric motors, including all wiring and control apparatus, weigh about 60 kg. (132.5 pounds) per horsepower hour at the same rate of discharge, or the total weight for the electric propulsion is 214 kg. (472 pounds) per horsepower hour.

He gives a table comparing capacity and other characteristics of the lead and Edison batteries.

Arnold's[67] (1912) article is a repetition and extension of a publication by Bezzi and Bartoli in the *Revista Marittima* for January, 1912, on the use of electricity in submarines.

The reasons for adopting accumulators for submerged propulsion are discussed.

The power of various batteries is shown by tables:

Type of submarine	Displacement, tons	Power of motors, horsepower	Power of battery, kilowatts	Capacity of batteries, kilowatt-hours
Hoalen (Swedish)	250	220	180	540
Velella (Italian)	300	300	246	738
Trasher (United States) ..	450	415	340	1020
Mariotte (French)	1000	800	650	1950

The types of batteries are compared as follows:

Type	Per kilowatt-hour on three-hour discharge			
	Weight, kilogrammes	Volume, cu. dcm.	Price, marks	Discharges before wearing out
I. Lead, positive Planté plate	73.5	37	156	250
II. Lead, positive pasted plate	62.0	24	160	200
III. Same of greater capacity ..	56.0	19	152	150
IV. Iron-nickel, Edison	42.0	18	270	400
V. Same, Jugner	43.0	20	270	400

This makes the cost for average kilowatt-hour in marks:

I.	0.62
II.	0.80
III.	1.01
IV.	0.68
V.	0.68

The voltage generally used now is 110 or 220, though voltages of 440 have been employed in the past.

The precautions of insulation and ventilation necessary to safety are mentioned.

The characteristics of operation and advantages of the lead and Edison batteries are compared graphically and otherwise.

The motors serve as generators in charging the batteries. The points of importance in their choice and method of regulation are discussed rather fully.

Hoar[57] (1916) describes the make-up and nature of the plates used in submarine storage batteries. Only lead batteries have been employed up to the present time. The three forms used are the Planté, pasted plate, and ironclad plate.

One or two boats have been recently fitted with Edison batteries.

The lead battery is objectionable because of its weight, nearly 59 tons, the space which it occupies, and the poisonous and explosive gases it generates, and because of the acid electrolyte, which is liable to slopping over and will then attack the hull.

The Edison battery avoids only the danger of chlorine gas and leaking acid. At the three-hour rate of discharge it gives only 1.1 to 1.2 volts, compared with 1.83 volts for the lead battery, and consequently the number of cells used must be 60 per cent. greater. The weight is higher also. The Edison battery is more costly, but has a much longer life than the lead battery.

Robinson[11] (1915) gives very much the same data as Hoar,[57] describing the make-up of the plates used in the storage batteries. The voltage of the lead battery at the three-hour rate of discharge is about 1.84 volts, compared with 1.2 volts for the Edison. Hence for the same average total voltage, 192 of the latter cells should be required in place of 120 of the former. The Edison battery is the more bulky and heavy for the same power. The life is longer, though a nearly equal life is now claimed for the ironclad battery, but the cost is far greater.

Lake[5] barely mentions the batteries. He states that two types, the Planté all-lead, and another with pasted lead plates, are employed in submarines. Both use sulphuric acid and require ventilation during charging, as does also the recently announced Edison submarine battery. The last is said not to give off chlorine or any other poisonous gas when salt water gets into the batteries, an accident that has caused the loss of some lives in the past. Diagrams are given of the casing and ventilating cover.

III. ARMAMENT.

Torpedoes.—The effectiveness of the Whitehead torpedo and the difficulties to which it is subject are mentioned at some length by Biles[68] (1914). In the Russo-Japanese War only 5½ per cent. were effective hits, and no ship was sunk immediately by a single torpedo. There were only 2 per cent. effective hits on *moving* ships.

The torpedo is a very close range weapon and should be used within 400 yards. Speed is the battleship's best defence.

Special forms of armor are suggested. But fleets of small rapid boats are suggested as the most effective protection.

Dumas[69] (1915) describes in detail, with 13 illustrations, the mechanism and use of the Whitehead automobile torpedo, introducing his paper by a brief history.

He points out that the torpedo is peculiarly the weapon of the submarine because of the latter's ability to get within the very short range (800 to 900 metres) necessary, before detection. Although most of the battleships destroyed in this war have been sunk by torpedoes, yet at the battle of Heligoland many torpedoes were launched by both German and English ships without any of them taking effect.

The first Whitehead torpedoes were 356 millimetres in diameter, 4.42 metres long, weighed 272.9 kilogrammes, and carried a charge of 18 kilogrammes of gun-cotton. Their range was 400 metres at 20 knots or 37 kilometres per hour. Modern torpedoes are generally 0.450 metres in diameter, as long as 6.6 metres, weigh 70 kilogrammes, and carry a charge of 100 kilogrammes. Their range is 1000 metres at 43 knots or 8000 to 9000 metres at 28 knots. Some navies use torpedoes of 500 and 533 millimetres diameter, carrying 150 kilogrammes or even more of explosive.

The Whitehead torpedo, in its various modifications, is the one almost exclusively employed, although the United States Navy also uses the Howell torpedo.

The arrangement and operation of the Whitehead torpedo are given in considerable detail. It is propelled by compressed air, under 85 to 150 kilogrammes, whose temperature during expansion is maintained by the burning of gasoline. Excessive temperatures are prevented by the injection of a spray of water. Further details are given in the original. The motor is of the Brotherhood type and has four cylinders.

The regulating and directing devices, propellor, stabilizing gyroscope, etc., are fully described.

The torpedo generally runs at a depth of 3 metres, but can be regulated for much smaller depths. The Germans have used one running at less than 1.60 metres.

The launching tube is shown and its operation explained.

Michelson[70] (1913) describes and shows the construction and operation of the Whitehead torpedo, which, he states, is used internationally. The charges of explosive now used are from 120 to 150 kilogrammes. Picric acid and trinitrotoluene are the most commonly used.

The English 55.3-cm. torpedo will run 10,000 to 11,000 yards. Its effective range is probably only 6000 metres. The motive power is compressed air. Gasoline can be used, but is apparently not advantageous. The article gives details of construction and of progress in efficiency since the early types.

The depth variation in the course of the torpedo is very slight —only a few centimetres—but its sidewise variation is about one per cent. of the distance run.

The Davis torpedo differs only in its head, which is such as to cause the force of the explosion to be expended within the hull of the vessel attacked. It follows in its course the line of the tube from which it is fired.

Modern French submarines already carry seven tubes.

In the discussion it was brought out that torpedoes similar to the Whitehead are manufactured by Schwartzkopff in Germany, and the German marine has also developed a slightly different and much improved type.

The gyroscope and heating apparatus are especially important to further development.

Reference[71] (1913) gives a detailed description, of the mechanism, method of operation, method of firing, and use of the torpedo. The air heater is described. Pictures are shown of parts, etc., of the Whitehead, Schneider, and Woolwich types of torpedoes. The article is a good condensed statement.

Heinz[72] (1909) goes into great detail over the heating of the propelling air in the automobile torpedo. He gives the history of this development, with details of its application, cuts of apparatus, etc., in different systems, and comparison of the resulting efficiencies of the torpedo.

Bernotti[73] (1913) solves mathematically the problem of aiming torpedoes both for single and broadside firing.

Pramer[74] (1914) treats of the torpedo and its use in war in an article of 146 pages, illustrated with diagrams. He points out in the beginning that, because of its recent and extremely rapid development, the effectiveness of the torpedo has never been thoroughly tested. All practicable tests outside of actual warfare are entirely inadequate. Recent improvements, particularly in regard to range, velocity, steering, and weight of explosive charge, have been very great.

He then describes the status of the arm in the summer of 1913. It is impossible to review the different types of torpedoes. Each navy keeps its own construction, the outcome of experience, secret. Published data are very scanty.

The Whitehead torpedo made at Fiume, was operated by unheated compressed air at an initial pressure of 150 atmospheres. It was of 45 centimetres calibre, 2¼ metres length, carried 90 to 100 kilogrammes of explosive, and had a maximum range of 3000 metres at a velocity of about 23 to 24 nautical miles per hour at a depth of three metres. For 1000 metres it had a velocity of 34 miles per hour. Heating the propelling air increased the range to 1500 metres at 40 miles per hour, or 6000 metres at 28 miles per hour. This improvement in the propulsion made possible an increase of calibre. England and Germany increased to 53 centimetres and France to 60 centimetres.

The modern English Hardcastle torpedo, which was brought out about two years ago, is another advance, whose improvement is made possible by increase in length. Its range is 9000 metres at 30 nautical miles per hour, or 1000 metres at 45 miles per hour, and it carries 130 kilogrammes of explosive. It is reported that the most recent modification of this torpedo has a range of 9900 metres at 30 to 40 miles and carries 150 kilogrammes of explosive.

The German product has already attained, in the 60-cm. torpedo of nine metres length, a sufficient speed for 12,000 metres, and for 100-metre runs at 52 nautical miles per hour. The heating device has been improved, probably by addition of an oxygen cartridge, so that the fuel is fully utilized.

The American 53-cm. torpedo with a hot-air turbine drive should give great economy at high speed, but is not reported to be very satisfactory. It stands far below the English and German. It carries 145 kilogrammes of explosive and has a velocity of 40 nautical miles for 1500 metres, 30 miles for 4000 metres, and 25 miles for 5000 metres.

Of torpedoes with explosion-motor drive, the technical press reports that Japan has one of 60-cm. calibre, with a gasoline motor and a range of 12,000 (?) metres at about 30 nautical miles per hour.

The torpedoes of the French marine, like the Whitehead torpedo, have ranges of 1000, 2000, and 3000 metres at 40, 34, and 29 nautical miles respectively. The straying of the Whitehead was less, being 0.6 per cent. at 1000 metres, 0.75 per cent. at 2000 metres, and 0.83 per cent. at 3000 metres, against 1 per cent. of the distance passed over for the French torpedo.

The French use two types, one for long range with light machinery, large air flask, and not very high speed, the other for high speed. The first goes 8000 metres at 28 to 30 nautical miles per hour.

England and Germany use one type, with the highest speed possible with high explosive charge.

The Davis torpedo, an American type, is designed to break its way through protecting nets by means of the explosion of a small charge, without affecting the main charge of explosive.

The use of the gyroscope marked a great improvement in the torpedo. Without it constancy of direction could be obtained for about three minutes, sufficient for the range of the torpedo, without heating apparatus or steam injection, at a velocity of 25 nautical miles per hour. With range extended to 5000 metres a better direction regulator became necessary.

A seven-minute constancy is necessary for 6000 metres at 30 miles. For torpedoes of over 6000 metres range the English and German navies use an electrically-driven directing apparatus.

Recently a new gyroscope has made possible launching from a tube at an angle with the course of the torpedo. It makes possible the use of fixed tubes placed to good advantage in the boat.

The explosive mostly used is wet gun-cotton, as this has the most favorable properties in regard to lack of sensitiveness toward jar and temperature change, stability, etc.

Forty-five-centimetre torpedoes take 93 kilogrammes and 53-cm. 113.5 kilogrammes of explosive.

The modern torpedo explodes, whatever the angle at which it hits its target.

The latest Whitehead torpedoes had in the spring of 1913 the following characteristics:

Calibre, centimetres	Range, metres		Speed, nautical miles per hour	Lateral deviation at fixed target, metres	Maximum range, metres
45	1500	at	40		
	6000	at	27		
53	3000	at	38	20	
	5000	at	31	50	7000
45	2000	at	44.6	(Two-cylinder motor)	
	6000	at	30.3		

The total deviation at 2000 metres was about half the length of a modern ship going at a speed of 18 nautical miles per hour. In hot-air torpedoes a velocity variation of 1.5 nautical miles was tolerated, or, including the lateral deviation, a total of about two nautical miles per hour. A torpedo with a velocity of 40 miles goes about 2000 metres in about 100 seconds. A variation of two miles per hour equals a variation of 100 metres in the time that a boat travelling at 18 nautical miles would move 45 metres. This makes the extreme range under these conditions 2000 metres when all is favorable.

Pramer goes into the details of the methods of using the torpedo as a weapon in war, at very great length. (He considers the principles and mathematics of range finding and aiming, and illustrates with many diagrams.) His chapters are headed:

II. Launching in General Without Consideration of Tactical factors.

III. The Target.
IV. The Torpedo Carrier.
V. Short-range Use.
VI. Long-range Use.

Reference[75] (1912) describes with illustrations the Davis torpedo. This includes, within the limits of an 18-inch 5-metre torpedo, a gun of 8-inch calibre, firing an explosive shell of 215 pounds with an increase in weight slightly less than an augmented charge of gun-cotton. This projectile has a muzzle velocity of 1000 foot-seconds. It is capable of penetrating 4- or 5-inch armor plate of hardened steel. So far as known, the bulkhead defence against torpedoes of none of the battleships built to date is thicker than 1.77 inches, and the average is 1.5 inches.

Vergnier[76] (1911) describes the construction and testing of the three types of Schneider torpedo which are used by the French Navy. In addition to the usual details, he mentions that the temperature in the cylinders of the motor does not exceed 200° since the injection of water has been employed.

The testing station at Hyères is described in detail.

Gray[77] (1914) gives the fundamental mechanics underlying the behavior of the gyroscope, and simple illustrations of its action when applied to various devices.

Gray[78] (1914) gives the simple principles for the application of the gyrostat to controls for torpedoes, submarines, etc. He analyzes the forces involved and gives graphic illustrations, and mentions the possibility of further use in very high speed, long-distance torpedoes.

Biles[68] suggests the possibility of protecting battleships from submarine attack by armor plate four inches thick on the bottom. This would reduce the speed about two knots. In the discussion a number of points are brought out.

Guns.—Schiffbau[79] (1913) states that the Krupp light gun equipment consists of the 3.7-cm. gun with total weight of 265 kilogrammes. The heavy equipment consists of a 7.5-cm. gun with a total weight of 860 kilogrammes. Both are so mounted that they can be closed down into the space between the deck and the hull. They require the service of two or three men each. Details of mounting are given. The guns are made of high-percentage nickel-steel to resist corrosion, since the compartment is not water tight.

Reference[80] (1914) describes with illustrations the two types of Krupp guns carried on submarines—the disappearing and the permanently mounted. The latter must be small (37 mm.) to avoid high resistance. Both are made of non-rusting nickel-steel. The larger gun is a short, powerful 12-pounder of 75-mm. calibre, capable of sinking a torpedo boat, and it can be fired vertically at an airship. This gun can be raised and fired in 20 seconds.

Bernay[16] (1912) states that the recent 800-ton German and English submarines are provided with 88- and 75-mm. guns respectively.

IV. SPECIAL EQUIPMENT.

Periscope.—Lake[5] (1915–16) mentions briefly the characteristics of the periscope, and says that the instrument giving normal image and a correct idea of distance dates from 1900. He intends to describe in a later article a device which he believes can be used at night when the present instrument is useless. He states that periscopes are now so made that the heavens as well as the horizon may be viewed.

Weidert[81] (1914) takes up at great length the construction and development of the periscope. The year 1906 brought such improvements in this instrument, as well as in other details of the submarine, that a great many of the previously insurmountable obstacles were overcome. Extensions of the field of vision, sharpness and brightness of the image, ease of observation, and the development of means of measuring the distance, marked that year. Mechanical improvements, such as the extending and withdrawing of the periscope, have followed. While all the early patents originated outside Germany, the modern construction is almost wholly covered by that country's patents.

The author reviews and describes the patents and developments from the earliest forms down to the complicated instruments of the present, with their many optical improvements and attachments. The material is too detailed and specific to abstract, and is also well illustrated.

Reference[82] (1916) describes the recently patented Parodi periscope.

Submarine Signalling.—Fay[83] (1917) describes the work of the Submarine Signal Company in developing means for signalling under water. Bells were used at first for the signalling instrument, and the signals were received by microphones installed in tanks filled with water, mounted on the ship's plates, one on each side of the boat. The microphone on each side was connected to a separate telephone receiver, so that comparison of the intensities served to give the direction of the sound received. In this form the apparatus was ideal as a fog signal, and was used to some extent for sending messages.

Introduction of the Fessenden oscillator has now produced a great advance, as it is more powerful and more rapid, and serves as both transmitter and receiver of signals. This oscillator is similar in principle to the telephone receiver, but magnified about 200 times. The diaphragm, 24 inches in diameter and several inches thick, is placed in contact with the water, to which it transmits its vibrations just as the telephone diaphragm does to air. The greater amount of energy required to make so heavy a diaphragm vibrate is supplied by a powerful electromagnet. The field magnets employed are energized by a direct current of 7.5 ampères and the diaphragm is set in motion by a current of 11 ampères at 180 volts on the windings of the core. The details of construction are given in full with a cut.

The oscillator operates at a frequency of 540 cycles per second. In receiving it is also affected by outside noises from waves, etc. Its maximum range of signalling is about 30 miles, and the average 5 to 10 miles. Signals are frequently sent at 20 words per minute.

The dimensions of the oscillator are about 30 × 16 inches, and its weight is about 1200 pounds. It is used in pairs, similarly to the microphone, and in submarines is placed in the forward ballast tanks, one on each side, low enough down so that signals can be sent and received when on the surface.

On ships the best position varies, but is about 15 feet below the water-line and not too near the keel. The microphones must also be near enough to the bow so that they face slightly forward.

At present the face of the diaphragm is so mounted as to form a part of the skin of the ship. The method of accomplishing this is shown by diagram, and cuts are given of the electrical apparatus required.

Perkins[84] (1914) gives a general review of the subject of submarine signalling by means of gasoline, electric, pneumatic, and hand devices, with cuts. It is claimed that these methods of signalling can be used to guide ships into harbor, to enable fishing dories to return to their ships, to enable submarines to manœuvre in flotilla, to make navigation in fogs safe, etc. The United States submarine *Octopus* was saved from collision with a towline, while running a submerged test, by such a signal from her tender.

Signals by bells are said to have been heard 27 miles. Such bells are used for guiding ships in fogs in the English Channel, and Irish and North seas. The signals are given by bells hung on tripods at the bottom of the sea and rung electrically from shore. Buoys with bells rung by the wave motion are used similarly.

The receiving apparatus for such signals consists of microphones attached to telephone receivers. The microphones, arranged in pairs, one on either side of the ship, are immersed in tanks containing water. These tanks are 16 × 16 inches or 18 × 12 inches on the surface, and are attached two-thirds of the distance from the water-line to the keel. Pneumatic and electric bells are used for signalling. The sound passes through the skin of the ship to the water in the microphone tank, which is not in direct communication with the outside water. The sounds from port and starboard microphones are transmitted separately to the pilot, who by comparing the loudness can swing the boat until the intensities are equal, when it will be headed directly toward the sound. The article is confused in expression and gives considerable trivial detail, such as total weights and overall dimensions of the signalling apparatus, etc., for different purposes.

Carter[85] (1914) gives a brief general account of the method of signalling under water. He speaks of Fessenden's oscillator and Berger's vibrating steel ribbon. He considers the problem as promising, but still in the very primitive stage. The part so far taken by the Submarine Bell Company of Boston is mentioned.

Cathcart[86] (1914) mentions the uncertainty of most forms of signalling during fog, and contrasts the variability of the air as a method of transmitting with the constancy of condition of the water. He says that the bell-signalling outfit of the Submarine Signal Company is now installed on about 1225 ships. The bells send out a sound of about 1200 vibrations per second, which is distinctive among the low-pitched noises of the ship. He gives Professor Fessenden's own description of his oscillator, with illustrations. At a frequency of 500 per second this delivers 35 kilowatts of mechanical power to the water at an efficiency of over 90 per cent. Signals can be sent by code and have been read at a distance of 30 miles with the receiver a foot from the ear, when using only 10 per cent. of the full power of the oscillator. Preliminary tests on sound reflection from icebergs and from the bottom are mentioned.

Blake[87] (1914) mentions briefly the advantage of submarine signals over other types. Even wireless does not indicate direction. Submarine methods do this, but the bell and microphone method have various objections, such as slow rate, etc. Many of these are overcome by the Fessenden oscillator. This apparatus is described and illustrated. It consists of an electromagnetically vibrated diaphragm weighing over 100 pounds.

It is stated that by use of this oscillator even telephony is possible, sentences having been transmitted 800 yards and conversation carried on at 400 yards with the use of an ordinary telephone with six dry cells. Signals have been heard a distance of 20 miles from a boat running at eight knots.

Other probable uses are the taking of soundings and detection of icebergs by the echo of tones sent out by the oscillator, the elapsed time indicating distances. Successful tests have been made of both of these uses.

Millet[88] (1914) states that the bell and microphone method of submarine signalling worked out by him in the nineties was quickly adopted by all the large transatlantic line companies, and submarine bells are now in operation at nearly 200 points on various coasts. The Fessenden oscillator has opened the way for a great advance, and provides a means of detecting icebergs at distances of one-half to two and one-half miles.

Millet gives a brief mention of earlier investigators of the general problem.

Sawyer[89] gives a similar account of the history and need for submarine signalling. He describes in a very general way experiments made by the United States Navy with the device of the Austrian, Berger, involving the vibrations of a steel wire or strip, and later with the Fessenden oscillator.

V. BUILDERS.

Boat Builders.—Aarestrup[90] (1913) gives the European firms which build or are building submarines, either on their own or licensed designs, as follows:

Firm	Location	Boats built
Electric Boat Company	Central office in Paris	about 165
Germaniawerf (Krupp)	Kiel	35
Fiat-San Giorgio	Spezia	25
Schneider	Creusot	10
Weserwerft	Bremen	1
Denny Brothers	Dunbarton	1

The following companies are also connected with the building of submarines:

Firm	Under license of
England:	
Vickers	Electric Boat Company.
Scott	Fiat Company.
Armstrong	Schneider Company.
Italy	
Orlando	For Fiat and license holders of Electric Boat Company.
Holland:	
Schelde	Electric Boat Company.
Russia:	
Newskywerft	Electric Boat Company.
Nicolaieffwerft	Plans of Russian engineers.
Lessner and Nobel	
Sweden:	
Bergsund	Swedish Marine Electric Boat Company.
Kockum	Fiat Company.

American:

Fore River Shipbuilding Company.[22]
Electric Boat Company.[22]
California Shipbuilding Company,[23] Long Beach, Calif.
L. A. Submarine Boat Company, Long Beach, Calif.
Snyder & Co. (French),[23] New York City.
International Submarine Shipbuilding Company, Maine.
Lake Torpedo Boat Company,[59, 23] Bridgeport, Conn.

Engine Builders.—The products of most of the following builders are described[59] (1917):

German:

Fried. Krupps, Kiel-Gaarden. Augsburg Works of Maschinenfabrik-Augsburg-Nurnberg. (Körting Bros. and others build moderate powered sets.) Nürnberg Works of M. A. N. (Designs at one time used by New London Ship and Engine Company.)

British:

Vickers, Ltd., Barrow. (Mr. James McKechnie, technical director.) Scott Shipbuilding Company. (Holds license from F. I. A. T. Company.)

French:

Schneider & Co., La Creusot. (M. Drosne, Chief Engineer.)
Augustin Normand & Co., Havre.
(Sabathé Company.) Société des Moteurs Sabathé, Usines de la Chaleassière, St. Etienne.
Société des Ateliers et Chantiers de la Loire.

Dutch:

Werkspoor Company, Amsterdam.

Danish:

Burmeister and Wain,[60] Copenhagen.

Italian:

Franco Tosi Company, Legnano.
Fiat-San Giorgio, Spezia.
F. I. A. T. Company, Turin.

Swiss:

Sulzer Brothers, Winterthur. (Busch-Sulzer Company, St. Louis, Mo., U. S. A.)

Swedish:

A. B. Diesels Motorer (?) (Polar Engine). (License owned by McIntosh & Seymour Corporation, U. S. A.)

Russian:

Kolomaer Company (?).
Maschinenfabrik Ludwig Nobel, Petrograd.

American:

Snyder & Co. (French),[23] New York City.
New London Ship and Engine Company, Groton, Conn. (Nlesco Engine.)
Busch-Sulzer Company, St. Louis, Mo.
James Craig Engine and Machine Works, Jersey City, N. J.
Southwark Foundry and Machine Company, Philadelphia, Pa. (Southwark-Harris engine.) (License bought by British Admiralty.)
McIntosh & Seymour Corporation, Own Polar license.

Reference[91] (1917) gives the following list of firms in the United States building Diesel engines, and the type produced by each:

DIESEL MARINE ENGINES.

Builders	Type
American Krupp-Diesel Co.	Krupp 4- and 2-cycle.
Atlas Gas Engine Co.	Atlas 4-cycle.
Bethlehem Steel Co.	Bethlehem-West 4-cycle.
Busch-Sulzer Co.	Busch-Sulzer 4- and 2-cycle.
James Craig Engine Works.	Craig 4-cycle.
Wm. Cramp Ship and Engine Co.	Burmeister & Wain 4-cycle.
Fulton Mfg. Co.	Fulton 4-cycle.
Gas Engine and Power Co.	Speedway 2-cycle.
McIntosh & Seymour Corporation.	Polar 4-cycle.
Newport-Weiss Shipbuilding Co.	Werkspoor 4-cycle.
New London Ship and Engine Co.	Nlesco-M. A. N. 2- and 4-cycle.
New York Navy Yard.	Nlesco-M. A. N. 2- and 4-cycle.
New York Shipbuilding Co.	Werkspoor 4-cycle.
Seattle Machine Works.	Seattle.
Seattle-Astoria Iron Works.	Troyer-Fox 2-cycle.
Standard Motor Construction Co.	Standard 4-cycle.
Standard Gas Engine Co.	Southwark-Harris 2-cycle.
Southwark Foundry and Machine Co.	Southwark-Harris 2-cycle.
Union Gas Engine Co.	Craig 4-cycle.
Union Iron Works.	Union & Nlesco 4-cycle.
Winton Engine Co.	Winton 4-cycle.
Wisconsin Motor Mfg. Co.	Wisconsin 4-cycle.

Many of these firms have built no engines as yet, and the list is largely of potential interest.

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II. *Propulsion.*

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[56] Berling, *Jahrbuch d. Schiffsbautechnischen Gesellschaft*, **14**, 109–155 (1913).
[57] Hoar, *J. Amer. Society of Naval Engineers*, **28**, 286–292 (1916).
[16] See Part I.
[58] Chalkley, *Cassier's Engineering Monthly*, **47**, 199–210 (1915); *J. Amer. Society of Naval Engineers*, **27**, 471–477 (1915).
[5] See Part I.
[1] See Part I.
[12] See Part I.
[59] Lisle, *Motorship*, **2**, (No. 4), 3–10 (1917).
[60] Shaw, *Motorship* **2** (No. 5), 17 (1917).
[32] See Part I.
[61] *Motorship*, **2** (No. 5), 15 (1917).
[62] Nimitz, *J. Amer. Society of Naval Engineers*, **28**, 487–497 (1916).
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[67] Arnold, *Schiffbau*, 13, 678–683, 728–732, 770–774 (1912).
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[72] Heinz, *Mitteilungen, Gebiete des Seewesens*, **37**, 662–684 (1909).

[73] Bernotti, *Revista Marittima*, December, 1912; *J. Royal United Service Institution*, **57**, 402–409 (1913).

[74] Pramer, *Mitteilungen, Gebiete des Seewesens*, **42**, 38–47, 226–248, 475–506, 580–596, 654–677, 765–800 (1914).

[75] *Engineer*, **113**, 205–206 (1912).

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[77] Gray, *Institution of Engineers and Shipbuilders in Scotland*, **57**, 121–146 (1914).

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[79] *Schiffbau*, **14**, 487–489 (1913); *Engineering*, **95**, 333–334 (1913).

[80] *Engineer* (L.), **118**, 506, 510 (1914).

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[81] Weidert, *Jahrbuch d. Schiffbautechnischen Gesellschaft*, **15**, 174–227 (1914).

[82] *Engineering*, **101**, 348 (1916).

[83] Fay, *J. Amer. Society of Naval Engineers*, **29**, 101–113 (1917).

[84] Perkins, *American Marine Engineer*, **9**, 29–33 (October, 1914).

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[88] Millet, *Trans. Society of Naval Architects and Marine Engineers*, **22**, 107–114 (1914).

[89] Sawyer, *Trans. Society of Naval Architects and Marine Engineers*, **22**, 115–122 (1914).

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[90] Aarestrup, *Schiffbau*, **14**, 860–863 (1913).

[22] See Part I.

[23] See Part I.

[59] See Part II.

[60] See Part II.

[91] *Motor Ship and Motor Boat* (English), **26**, 294–295 (1917); *Motorship*, **1**, (No. 8), 14 (1916).

The following books are a few of the most recent treating of the submarine. All are brief and non-technical in character. An exhaustive treatise seems to be lacking, in English at least.

TALBOT, "Submarines": their mechanics and operation. 1915. 264 pp. Van Nostrand Co.

This book, designed for the general reader, is a very good general treatment of the submarine, covering history, mechanism, operation, military functions, armament, etc.

HOAR, "The Submarine Torpedo Boat," its characteristics and modern development. 1916. 204 pp. D. Van Nostrand Co.

This book is a profusely illustrated treatise on the subject designed for the "general reader," as have indeed been practically all the books published on this subject. Hoar has, however, gone into considerable detail, and his book contains much valuable data. Ten pages are devoted to the torpedo.

DOMMETT, "Submarine Vessels," including mines, torpedoes, guns, steering, propelling and navigating apparatus, etc. 1915. 106 pp. London, Whitaker & Co.

This is a very brief and elementary outline of the main characteristics of the submarine which explains quite clearly the details of operation of the various appliances. It is intended for the general reader.

LAUBEUF, "Sous-Marins et Submersibles." 1915. 104 pp. Paris, Librarie de la Grave.

This book is a brief discussion of the salient features of the submarine—its history, types, use in war, future, and an account of the number, dimensions, armament, and speed of the German fleet.

Spontaneous Combustion of Oleic Acid Containing Iron. C. E. SWETT and W. S. HUGHES. (*Journal of Industrial and Engineering Chemistry*, vol. 9, No. 6, p. 623, June, 1917.)—A case of spontaneous combustion of oleic acid when applied to wool was recently observed in a mill. The wool or other hair fibres were first oiled with 10 per cent. of their weight of oleic acid, after which the oiled fibre was conveyed to bins through a tinned iron pipe by a current of air. The conveying pipes were very near a bank of heating pipes employed to heat the mill.

An analysis of the oil showed nothing of suspicious nature, but it was found that the finer fibres gave a greater rise of temperature. This fact was ascribed to more surface for oxidation with the finer fibres. To test this point cotton was tried, and a rapid and dangerous rise was found. As no such rise was found with pure oleic acid of pharmaceutical grade, it was apparent that something about the oleic acid was wrong, notwithstanding the results of the analysis. Briefly, it was found to contain 0.10 per cent. ferric oxide. An oleate of iron was next made and dissolved in the pure oleic acid, so that it contained the same amount of iron as the commercial sample. When this oil was applied to cotton it was found to give the same dangerous rise as the commercial sample. The small amount of iron had functioned as a catalyzer to promote oxidation.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

THE REFLECTING POWER OF TUNGSTEN AND STELLITE.[1]

By W. W. Coblentz and W. B. Emerson.

[ABSTRACT.]

THE reflecting power of tungsten and in the region of the spectrum from 0.5 to 6 μ was determined by comparison with silver, and by a new method employing a total reflection prism. Four samples of tungsten in the form of plane, highly polished mirrors were examined. The reflectivity of tungsten rises abruptly from 50 per cent. at 0.5 μ to 90 per cent. at 2 μ.

All samples of tungsten show sharp indentations at 0.8 μ in the reflectivity curve. A similar indentation occurs at 1.3 μ in the reflectivity curve of the pure metal, but not in an impure sample. The application of these data to the question of increasing the luminous efficiency is discussed.

The reflecting power of stellite rises from 65 per cent. in the visible to 88 per cent. at 9 μ.

STANDARD SAMPLES FOR THERMOMETRIC FIXED POINTS.[2]

[ABSTRACT.]

THIS circular (No. 66) describes the methods of preparation and the chemical analyses of the metals, tin, zinc, aluminum, and copper, which have been prepared by the Bureau of Standards for distribution.

The melting-points of these materials were determined with platinum-resistance thermometers, and will serve to define accurately certain fixed points of the temperature scale so that they may be used for the calibration of pyrometers, the samples distributed being sufficient in amount (about 50 cm.^{3}) for this purpose.

The metals are all of American manufacture and are probably of as high a degree of purity as has been attained in the preparation of relatively large amounts of such materials. The chemical analyses show purity as follows: Zinc, 99.993 per cent.; tin, 99.988 per cent.; copper, 99.987 per cent.; aluminum, 99.66 per cent.

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* Communicated by the Director.

[1] Scientific Paper No. 308.

[2] Circular No. 66.

TESTING OF CLINICAL THERMOMETERS.[3]

[ABSTRACT.]

The Bureau of Standards has just completed a revision of Circular No. 5 on the "Testing of Clinical Thermometers." This new edition, which is the third so far, announces the adoption of new regulations, effective January 1, 1917, governing the testing of clinical thermometers. Past practice was to issue certificates containing tables of corrections at four points, 96°, 100°, 104°, and 108° F.; the new certificates will be issued only for thermometers correct within 0°.1 F. at normal (98°.6), and 0°.2 at 104°, and will contain the statement that the thermometer is correct within these tolerances.

The circular contains a full description of the method of testing clinical thermometers and considerable matter of general interest concerning these instruments.

The question of accuracy in clinical thermometers is obviously an important one. The clinical thermometer bears the same relation to the physician as the weighing scale does to the merchant, but, in a way, the former is vastly more important, as it has to do with life itself.

It has been estimated that over a million of these little instruments are manufactured each year to replenish the supply, for a clinical thermometer is delicate and usually short lived. Unscrupulous manufacturers, taking advantage of this never-ceasing demand, place on the market thousands of unreliable thermometers which, on account of their cheapness and the fact that their defects are almost impossible of detection, find ready sale.

It is obvious that the Bureau cannot inspect all these thermometers, for it tests only those that are voluntarily submitted. This circular calls attention to the fact that thermometers of doubtful accuracy may always be checked at this Bureau, and that when a thermometer is offered for sale with a Bureau of Standards certificate its reliability cannot be questioned. If instruments of a high quality are thus demanded, in time the unreliable article will no longer be manufactured.

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[3] Circular No. 5.

AN ANEROID CALORIMETER FOR SPECIFIC AND LATENT HEATS.[4]

By Nathan S. Osborne.

[ABSTRACT.]

THE unstirred type of calorimeter has been embodied with important refinements in an instrument especially designed for determinations of specific heat and latent heat of refrigerating media. Heat developed and measured electrically is distributed automatically to the calorimeter and contents, whose temperatures are measured by a platinum thermometer. Heat from other sources is excluded by a null method.

The calorimeter is adapted for use between – 50° and + 50° C. in experiments where the measured heat added is used either to change the temperature of the contents or to evaporate a portion of the contents withdrawn as superheated vapor; in the first case the specific heat of the liquid and in the second the latent heat of vaporization being obtained when proper corrections are made.

THE RELATIVE SENSIBILITY OF THE AVERAGE EYE TO LIGHT OF DIFFERENT COLORS, AND SOME PRACTICAL APPLICATIONS TO THE RADIATION PROBLEMS.[5]

By W. W. Coblentz and W. B. Emerson.

[ABSTRACT.]

THIS paper gives data on the relative visibility of radiation of the average eye, based upon a group of 130 observers. The data were obtained by means of a flicker and an equality-of-brightness photometer. The energy evaluation of the light stimulus was made with great care.

The point of maximum visibility of the average eye is at $\lambda = .5576\ \mu$. A mathematical equation is given of the average visibility curve, which is applied in calculating the luminous energy emitted by a black body at various temperatures, and the mechanical equivalent of light. The eye responds to light having an intensity less than 1×10^{-16} watts per cm.^{2} The paper describes tests on diffuse light and on a physical photometer. A screen is described which transmits radiations proportional to the average eye.

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[4] Scientific Paper No. 301.

[5] Scientific Paper No. 303.

Curve Plotting with Logarithmic Coördinates. ANON. (*The Electric Journal*, vol. xiv, No. 7, July, 1917, p. 259.)—The advantages of logarithmic cross-section paper have been appreciated for many years by some engineers, but there is room for its more extensive use. Any exponential equation of the general form $y = kx^n$ will be a straight line when plotted on double logarithmic paper. Similarly, any equation of the general form $y = ka^{nx}$ will be a straight line when y is plotted logarithmically and x arithmetically. This characteristic is especially useful in plotting, for example, a series of hyperbolas, which, on arithmetical paper, must be plotted from a number of calculated points, while on logarithmic paper only two points, or only one point and the slope, are necessary.

An advantage of the logarithmic paper, not so widely recognized, is that it gives the same percentage accuracy over its whole range, in the same manner as a slide rule. With straight cross-section paper, if at a value of 15, a quarter of an inch represents a change of ten per cent.; the same distance gives a change of only one per cent. at a value of 150. On logarithmic paper, however, a given distance means the same percentage change on any part of the scale. A correlative advantage is the great foreshortening of the scale. It is practically impossible to plot values over a wide range on arithmetical paper; whereas with logarithmic paper the values between 1 and 2 are just as legible and have the same percentage accuracy as those between 1000 and 2000. Where the foreshortening effect only is desired, it is not necessary that the coördinates be the same scale. The abscissæ scale may be several times that of the ordinates; or they may be uniform, to represent time or other similar intervals.

Still another advantage of the logarithmic paper is that the slope of the line representing an exponential equation is proportional to the exponent. A variant of this advantage is illustrated by the curves in the article by Mr. C. E. Skinner in the JOURNAL OF THE FRANKLIN INSTITUTE for June, 1917. When the slope of a curve changes suddenly, a critical point is generally indicated; that is, a point at which some change in the structure or characteristics of the material being analyzed takes place. Such a change in curvature is difficult to notice on arithmetical coördinate paper or from inspection of the data. But even a slight change in the slope of a straight line is readily noticeable, so that such a critical point is much more apparent when the data are plotted logarithmically.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

PHOTOMICROGRAPHS IN COLOR.[1]

By Dr. C. E. K. Mees.

[ABSTRACT.]

LANTERN slides representing photomicrographs of stained sections should, in order to give satisfaction, closely resemble the appearance of the section itself. This can be attained by making the print in stained gelatine instead of by the usual photographic process.

The process of making such a print is as follows: Lantern plates (Seed or Standard plates are satisfactory) are sensitized by bathing for five minutes in a 2½ per cent. solution of ammonium bichromate containing 5 c.c. of strong ammonia to the litre, the temperature of the bath being not above 65° F. The plates are then rinsed for two or three seconds in clean water, drained, and dried as uniformly as possible, the plates being kept in the dark during drying. The sensitized plates are then exposed through the glass under the negative to the light of an arc lamp, the average exposure being about three minutes at 18 inches distance. Printing cannot be done by daylight, or sharp images will not be obtained. The exposed plates are then developed by rocking in trays of water at about 120° F. until all soluble gelatine is removed. Underexposure is indicated by the high-light detail washing away, and overexposure by the film being insoluble to too great a depth. The plates are then rinsed in cold water, fixed in hypo, and washed free of the hypo. They are then ready for staining.

The staining is done with a one per cent. solution of dye containing one per cent. of acetic acid, the dye being selected to simulate most closely the original stain of the section, the time of dyeing being chosen so that the necessary depth is obtained.

When sections stained with two different colors are being photographed negatives are made through suitable color filters and are then dyed in the two stains and placed face to face so that a two-color slide is obtained.

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* Communicated by the Director.

[1] Communication No. 50 from the Research Laboratory of the Eastman Kodak Company, published in *American Photography*, 1917.

Suppose a section is stained red and green. Two negatives are made on panchromatic plates—one with a red filter, which will cause the green to appear as clear spaces in the negative and will not record the red, and the other with a green filter, which will record the red and not the green. The slides made as described from these in bichromated gelatine are stained—that from the red negative with the original green stain, and that from the green negative with the original red stain.

The filters required can be chosen from the set of filters for photomicrography prepared under the name of Wratten M filters. The choice of the filter is decided by visual trial under the microscope, the filters chosen being those which most nearly absorb one color and transmit the other. Thus, photographing a section stained with Delafield's hæmatoxylin and precipitated eosin, the A filter (red) shows no trace of the eosin and gives a good, strong negative of the hæmatoxylin. The B and C filters are used together for the other negative, giving a blue-green color and recording the eosin and hæmatoxylin both fully, and from these two negatives positives are made and stained with a blue and a red dye.

NOTES FROM RESEARCH DIVISION, ELECTRICAL ENGINEERING DEPARTMENT, MASSACHUSETTS INSTITUTE OF TECHNOLOGY.*

EXPERIMENTS TOWARDS DETERMINING THE MAXIMUM EXTERNAL POWER OF ATHLETES.

It is sadly remarkable that, in spite of all our world's records of various athletic events, we are almost wholly ignorant of the maximum external power which a strong man is able to exert; *i.e.*, the maximum rate at which he is able to do mechanical work. This is a matter of importance from humanistic, statistical, physiological, athletic, and engineering standpoints. Some experiments in this direction have recently been made by a group of students,[1] and particularly by Messrs. Norman B. Ames and Lucas E. Schoonmaker, who made a thesis study of the subject.

The experiments were made by observing the time in seconds required to run up to different heights on a flight of stairs. The work done externally by the subject being equal to his weight multiplied by the difference of level from start to goal, the average power developed during the run is this amount of work divided by the observed time.

It was found that, taken from a standing start, the power developed increased rapidly as the height of the goal increased, until about four metres was reached. Increasing the climb beyond that height increased the power, but less rapidly. When the height of the climb was set at nearly nine metres, the power of the best athlete over the course reached a maximum, and in trials at yet greater heights the power fell off, owing to fatigue.

The best athlete weighed, clad, 76.5 kg. The work done in lifting his weight 8.83 metres was thus $8.83 \times 76.5 = 675$ kg.–m. The time of ascent being six seconds from standing start, his averaged power was 112.5 kg.–m. per second, or 1104 watts. An athlete can therefore develop an external power of 1.1 kilowatts, or about 1.5 horsepower.

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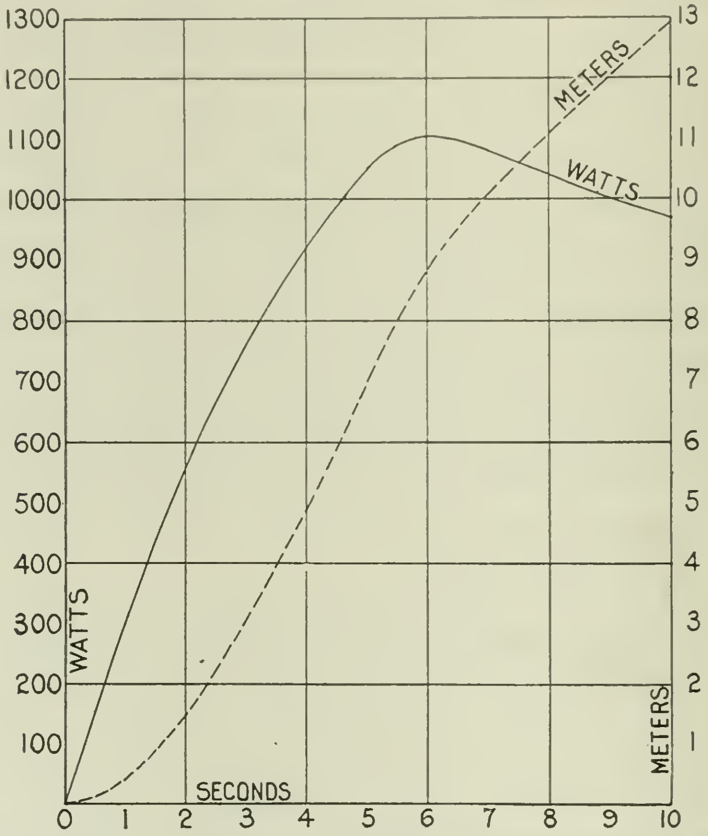
* Communicated by the Director.

[1] For further particulars, see "The Horsepower Race," *Scientific American*, vol. 117, July 7, 1917, p. 12.

The accompanying curve sheet presents, by the heavy line of "watts," the power developed by this athlete in different intervals of time from successive trials; *e.g.*, 550 watts in a climb of two seconds' duration, 1000 watts in 4.7 seconds, and 970 watts in 10 seconds. The broken line presents the height attained in different intervals of time as found in the same series of successive trials; *e.g.*, 4.9 metres in four seconds, 8.83 metres in six seconds, 12.9 metres in 10 seconds. The watts curve varies with different athletes, both in its maximum and in the time to reach a maximum, but it seems to have the same general shape in all of the cases thus far observed.

FIG. 1.



Average powers of a selected athlete over ascents of different durations up to 10 seconds. The broken line gives the corresponding elevations attained. Weight of athlete, 76.5 kg. (168 lbs.).

The results were obtained without any special training on the part of the athlete. They are therefore likely to be improved upon, and perhaps greatly improved upon, by selected athletes training for the event. It would be interesting to have such records accumulated.

The experiments were made on stairways in various places within Boston and Cambridge, Mass. The inclination of the stairway did not noticeably affect the results between the limits tried of 27°.4 and 37°.4.

It appears from world's records that in running contests over level ground the highest average speed over the course is attained in the 100-metre dash[2] (110 yards). This race has been run in 10.6 seconds with an average velocity of 9.43 metres per second. At shorter distances the speed is kept down by starting inertia, and at longer distances by fatigue. It is also known that the time of exhaustion or goal reaching, in all of the world's record events depending on speed (except cycling), varies approximately inversely as the ninth power of the speed over the course.[3] From the climbing records here reported, the best average speed is developed in about six seconds, with an average vertical velocity component of 1.47 metres per second; but these can only be regarded as preliminary indications. Many more observations will be needed to establish, to a satisfactory degree of precision, the maximum power which an athlete is capable of developing externally. The contest can readily be made competitive and spectacular. Perhaps only in active competition can the best maxima be secured. The leg muscles are manifestly the principal sources of the power developed in an uphill dash of this kind. It might therefore be possible to increase the output by providing balustrades along the stairway, with projections for enabling the athlete to urge himself upwards also by his arms.

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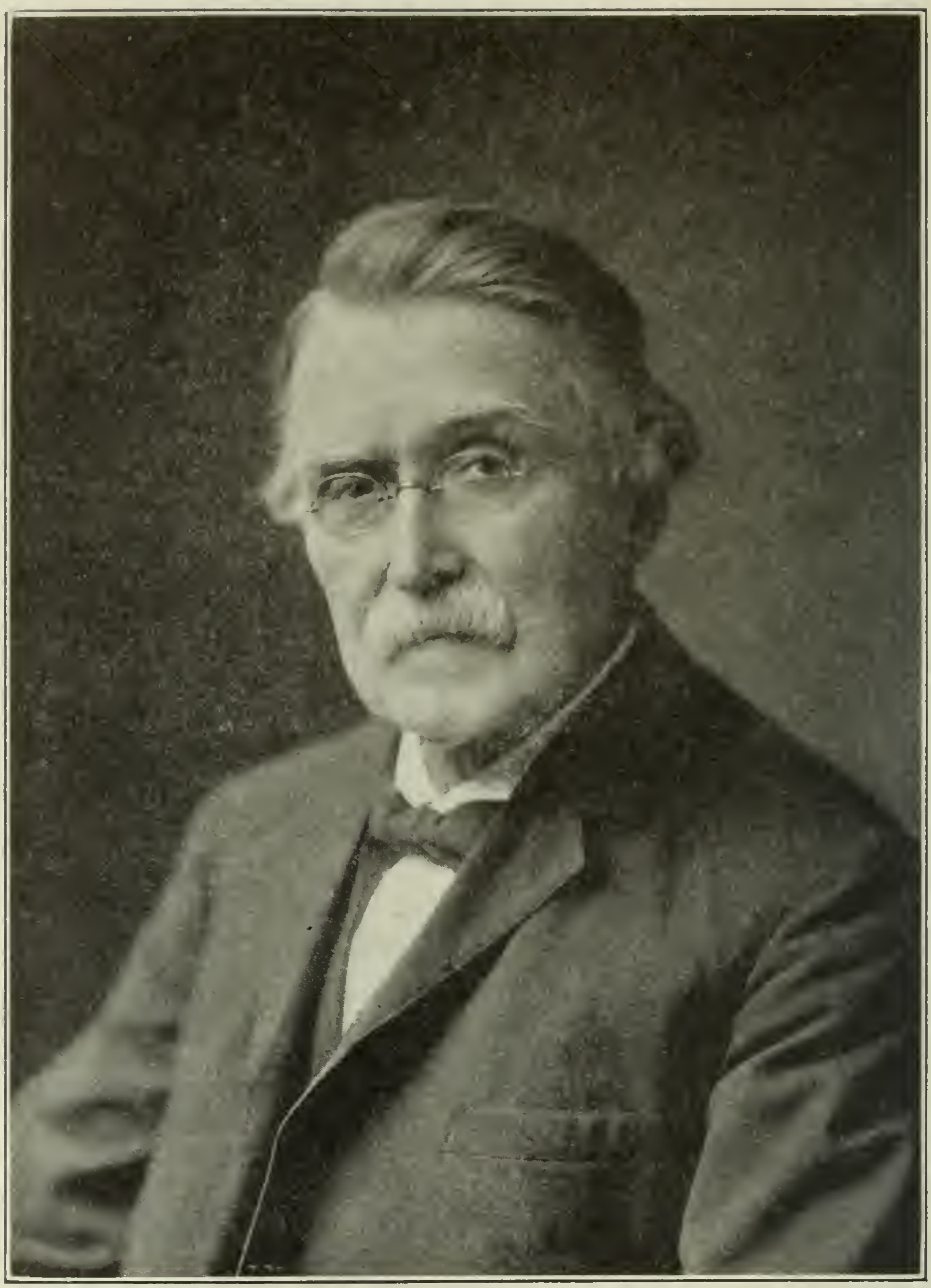
[2] "The World Almanac and Encyclopedia," 1917, p. 391.

[3] "An Approximate Law of Fatigue in the Speeds of Racing Animals." *Proc. of the American Academy of Arts and Sciences,* vol. 42, No. 15, December, 1906, p. 275; also, "Deductions from the Records of Running in the Last Olympiad," *The Popular Science Monthly,* November, 1908, p. 385; also, "A Law of Record Times in Racing," *Nature,* March 14, 1907, p. 463.



FREDERICK GUTEKUNST
1831–1917

THE FRANKLIN INSTITUTE.

NECROLOGY.

FREDERICK GUTEKUNST.

1831-1917.

The death of Frederick Gutekunst, on the 27th of April last, in the 86th year of his age, severed perhaps the last remaining link between the earliest years and the present of the photographic art. He was the Nestor of American photographers, a leader in the earliest varied applications of his art, and one who through a period of more than a generation stood as the most widely acknowledged master of photographic portraiture in America. In that field he held to the day of his death a place of marked distinction, and long ago had gained, through the sterling quality of his productions, a reputation which made his name to signify in reality, as well as literally, "good art."

Frederick Gutekunst was born September 25, 1831, in Germantown, the son of a German cabinetmaker who had settled in that suburb of Philadelphia. In his twelfth year he was diverted from his courses in the public schools to become a lawyer's apprentice in the office of the then Prothonotary of the Supreme Court, Joseph S. Cohen, to whom his father indentured him for two successive terms of three years each. During these six years, however, his natural bent to science rather than to learning became more and more pronounced. It had led him to spend more than half of his allowance of six cents per day for lunch on chemicals instead, and so, in his eighteenth year, he turned from the lawyer's office to become a drug clerk in Avery Tobey's apothecary shop at 1215 Market Street. There he put in the two next years and studied what had up to that time been discovered of photography and electricity. He then, as a youth of twenty-one, became a member of The Franklin Institute, utilizing its facilities to continue his studies in his favorite field of science. At the same time he turned from the drug business to that of photography, making daguerreotypes at first, and later applying the collodion process on glass for the production of ambrotypes. He also took up the then seemingly promising experiments for the turning of daguerreotypes into printing plates by electrolytic etching, but found, as did others at the time, the later collotype process to be more serviceable in the application of photography in the printing press. This method he early brought into practical use commercially, subsequently developing that branch into a separate establishment at Ninth Street and Girard Avenue. During the eighties this plant, in charge of a manager, proved unremunerative and was finally given up. Gutekunst would not leave his gallery; there he continued his lifework, gaining new distinctions to the number of 36 medals and diplomas and winning new laurels as the years went by.

There was nothing impressionistic, but much that was impressive, in Gutekunst's way with the camera. Whether he applied it to the production of such a picture as the panoramic view of the Centennial Exposition buildings in 1876, which gained for him not only royal decorations from the sovereigns of Austria and of Italy but also the appreciative recognition of the most accomplished experts of that day, or a picture of the Capitol at Washington at the same period, which remains to this day a standard presentation of its imposing subject, or whether he used it to produce a portrait, the result was a picture in which every feature was presented in the way that the normal eye would see the original under normal conditions and in a normal light.

There were not wanting at any time since the discovery of photography by Daguerre in 1839, and increasingly after the introduction of the collodion process in the fifties, photographers who sought to apply the camera for the production of "artistic," as distinguished from "realistic," effects, especially in portraiture. Paris early took the lead in this direction, and in time photographers in all the principal cities of Europe and America were vying with each other in the production of artistically posed and peculiarly lighted portraits, the so-called "Rembrandt effect," in which the lights of the picture were made subordinate to the shades, coming greatly into vogue, with less acceptable vagaries becoming here and there, for a time at least, the imprimatur of "quality."

In the midst of all these movements, however, Gutekunst kept on the even tenor of his way. He took the lead in his chosen field as the champion of "straight" portraiture. He insisted on making photographic portraits that were true to nature, with no attempt at anything but perfection in that respect. And that he certainly attained. He realized at once the limitations and the possibilities of the photograph as a register of physiognomy. The interpretation of physiognomy he left to the painter, whose translation of the original, as is the nature of translations, inevitably expressed somewhat of the translator's psychology, sometimes adding to, more often subtracting from, the original, and always more or less dissembling it. Gutekunst knew that a portrait could be idealized in the photograph no less than in the painting, but that the essential element of a portrait was its fidelity to nature. He realized that the artist's genius had not been supplanted by the camera nor his skill by the unconscious processes of chemistry, but that these agencies had given the artist a new potency in the attainment of a highly desirable end.

Gutekunst sought to produce a picture that would be a true presentment of his sitter's natural self, a photograph that would be a record of the sitter's normal mood, a portrait which would express, so far as a portrait can express, the sitter's innate characteristics, and he succeeded to a remarkable degree in the accomplishment of that purpose. So great was his success in that direction that he became famous as a "photographer of men," and likewise for the great number of his portraits of other famous men. Probably no other photographer has ever had so many of the leading men of his generation as sitters before his camera. During the Civil War so many of the officers of the army and navy and of the civil government flocked to his gallery that he became reputed at that period as the "official photographer," and from that time through all the succeeding years he maintained the high reputation which his earlier work had gained for him, and his place on Arch Street near Seventh continues to figure as a gallery of photographic portraits of leading men. There he worked in faithful devotion to his art through all the sixty years from November, 1856, when he started out on his definite course, steadfastly to within a few weeks of the close of his long and eminently useful life. His two daughters and a sister survive him.

Gutekunst combined an even-balanced mentality with an equally well-balanced temperament. Serious yet genial, dignified yet modest, his personality commanded the respect and gained the affection of all who came in contact with him. "F. Gutekunst," as he always signed himself, had come to be regarded as an institution in Philadelphia, and as such he will long be remembered.

LOUIS EDWARD LEVY.

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BOOK NOTICES.

Examples in Battery Engineering, by Prof. F. E. Austin, E. E., Hanover, N. H., published by the author, 1917. 90 pages, 39 illustrations, 4¾ × 7½ inches. Price, $1.25.

Almost any person of average intelligence can bungle through a technical problem, but commercial efficiency and discriminating judgment come only with that familiarity acquired by extensive drill work. Although there exists considerable literature on batteries, either in special monographs or in general treatises, there is probably no one work available from which commercial proficiency in the increasingly important subject of battery engineering may be attained.

The characteristic feature of this useful little volume is the large number of business-like examples of how batteries may be arranged for given purposes and output, and their possibilities and limitations. A number of instructive curves are plotted and explained, showing the laws of variations of the different quantities. No attempt has been made to enter generally into the details of the component elements of batteries, though a short reference is made to the constructive elements of storage batteries. Brief but adequate space is devoted to principles and the use of the various constants employed in battery work. A perusal of this text should prove of decided value to any electrical student who wishes to acquire dexterity in dealing with battery problems.

LUCIEN E. PICOLET.

THE LIFE OF ROBERT HARE, AN AMERICAN CHEMIST, by Edgar Fahs Smith, Provost of the University of Pennsylvania. Philadelphia, J. B. Lippincott Company, 1917. 508 pages, illustrations, plates, portraits. 8vo. Price, $5.

During the first half of the nineteenth century the name of Robert Hare was one to conjure with in American scientific circles. His brilliant achievements as a chemical investigator and his original contributions to chemical philosophy were highly esteemed and much admired, yet, nevertheless, it may be doubted whether his contemporaries (with the exception of a few of his intimates) had any idea of the real value of his unique achievements as a pioneer in the fields of high-temperature research and electrochemistry. Here and there some quaint and ingenious apparatus devised by him may still be found among the lecture equipment of schools and colleges; but apart from such curiosities, there was little that remained to recall to the present generation the importance of Robert Hare's contributions to physical science until a few years ago, when Provost Smith, in his interesting book, "Chemistry in America," once more called attention to the fundamental character of this Philadelphia chemist's discoveries and inventions. In the present volume Doctor Smith now presents an intimate and fascinating account of the life and labors of Hare, and his narrative is largely based upon, and liberally interspersed with, the hitherto unpublished letters of his subject and other practically forgotten documents. A mere glance over the pages of this splendid volume suffices to impress us with the fact that in writing it the author performed a labor of love: it is a biography not unlike those which Grimaux gave us in his "Life of Lavoisier," and Jacob Volhard in his "Life of Liebig." It is a beautiful, sympathetic, and sincere tribute to a great man of science by one who has achieved great distinction in the same field of endeavor and in the same institution of learning. A careful perusal cannot fail to convince the reader that not a few of Hare's discoveries have laid the foundations of great technical achievements and industries in our own time. Among these may be mentioned the invention of the oxyhydrogen blowpipe, by which the modern platinum industry and the Drummond light of the ocean lighthouses were made possible; the *calorimotor* and the *deflagrator*, by the aid of which their inventor obtained such substances as metallic calcium, calcium carbide, phosphorus and graphite (*i.e.*, substances which have only recently become most important products of the electrochemical industries). Hare was also the original inventor of the mercury cathode, which now plays so important a rôle in the electrolytic manufacture of alkali and its by-products.

In typography, paper, and binding this volume leaves nothing to be desired. It is adorned with a fine portrait in color of Hare and with several double-tone illustrations. The reviewer knows of no biography of any American scientist which surpasses this either in interest or in attractiveness of appearance.

HARRY F. KELLER.

GRANDES VOÛTES par Paul Séjourné, Ingenieur en Chef des Ponts et Chaussées. Paris, Tardy-Pigelet et Fils. In six volumes, paper; 1732 pages, 1230 illustrations, tables, 10 x 13 inches. Price, 250 francs.

Probably the most monumental engineering treatise in any language is this work on "Great Arch Bridges," by the eminent French engineer, Monsieur Paul Séjourné. The limited space allotted to this review does not permit of more than a passing reference to a few of the salient features of the book.

M. Séjourné illustrates and discusses practically all of the important masonry and reinforced-concrete arch bridges of the world, in six volumes, which are a model for technical writers in all that relates to clearness, thoroughness, elegance of diction, and high standard of finish.

The illustrations are profuse and artistic, and are exceptionally well reproduced; and the general mechanical make-up of the work is of the highest order. The first four volumes consist essentially of tabulated matter and illustrations. These tabulations are worthy of the highest praise, containing, as they do, practically all the information that any reader could desire. The preparation of these tables alone must have necessitated many years of hard work and the taking of infinite pains. A conscientious study of the illustrations alone, even if the engineer does not read French, would in itself be a liberal education in the æsthetics of bridge design. Reference to this book by any American engineer contemplating the making of a design for a concrete arch bridge could not fail to be productive of very material help and benefit; and the æsthetics of bridge designing in this country would undoubtedly be greatly improved by a general familiarity with this work on the part of our structural engineers.

Many American engineers may consider the high price of this set of books to be prohibitive of personal acquisition, because they have been spoiled during recent years by the issue of so many fine American technical works at exceedingly low prices; but the librarians of the public libraries in our large cities should certainly purchase this treatise for reference-use by engineers; and our universities and technical schools should not fail to order it for their libraries. Whenever an important technical work like "Grandes Voûtes" is published, the benefit of the profession not only demands that its value should be realized and that it be utilized to the utmost, but its employment and recognition would in some measure be an acknowledgment and encouragement to the author for his laudable efforts for the good of mankind. Such recognition and encouragement are much needed by technical book writers, because the labor and expense of preparing the manuscript are very heavy, and the pecuniary reward is almost always *nil*.

J. A. L. WADDELL.

PUBLICATIONS RECEIVED.

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CURRENT TOPICS

Outwitting the Deadly Torpedo. Anon. (*Shipping Illustrated*, July 14, 1917, p. 27.)—It is always a thankless task to throw cold water upon the enthusiasm of neophytes who attempt to solve problems that baffle the mind of trained experts in ship construction, particularly when such efforts have as their object the devising of means to reduce ship losses by affording protection against submarine attack. Numerous have been the makeshifts proposed in order to afford merchant ships some measure of immunity against the torpedo, and, while scientists, naval constructors, and others have so far produced nothing which they would conscientiously recommend as a panacea, a host of amateurs have come forward with schemes which have gained in popularity through advertisement that which they intrinsically lack in merit. It is not only a sheer waste of time to experiment with mechanical puerilities, but a source of danger, because popular enthusiasm might be wrought up to such a pitch as to force the adoption of this or that device before any steps had been taken to demonstrate, by experiment, the fallacy of the premises upon which it had been evolved. These remarks are suggested by the exhibition, in the New York offices of the Salvage Association of London, of a torpedo defence for merchant ships, which consists of steel plates suspended about 12 feet apart from the ship's sides along the machinery space. The plates are about three-eighths inch thick, suitably braced and suspended on each side by outriggers. The protecting device is from 15 to 20 feet deep, the top edge being five feet below the surface of the water. These plates are in the form of panels so that they can be roused out or stowed home alongside the vessel in sections by the aid of hauling lines to the deck winches. The claim made by this defence is that a torpedo would explode on impact with the plate, and the intervening cushions of water between the panels and the side of the ship would absorb the explosive energy of the torpedo's warhead.

Probably the well-meaning people who have endorsed the steel plate defence scheme have no conception of what a high-speed projectile of the modern torpedo type, weighing 2700 pounds and charged with over 300 pounds of trinitrotoluene, is capable of doing, even if exploded at a very considerable distance from the side of the vessel. What the torpedo has proved itself incapable of doing at a distance of from 32 and, in some cases, 50 feet from the side of the vessel certainly cannot be done by a rigid device of the character described. In conclusion, it is well to inform the public that the Navy Department has warned inventors against wasting time and energy on the production of torpedo-defence schemes which contemplate fastening shields or plates, movable or otherwise, or masses of elastic material, on the outside of a vessel in the hope of either warding off the torpedo or causing it to expend its explosion harmlessly. Wire nets are used when the ship is at anchor, in perfectly smooth water, or moving very slowly, but they are practically of no avail in heavy seas, and, besides, are liable to be torn off and foul the screws. In many instances, also, they have been found easily penetrable by a high-powered torpedo. It is equally useless to arrange big electromagnets on a vessel for the purpose of making the torpedo swerve and so avoid the ship. They have an unfortunate tendency—supposing they work at all—to attract the torpedo to the ship instead of deflecting it. But, of all schemes, perhaps the most frivolous is for untrained minds to try to devise novel methods of ship construction for the purpose of enabling ships to keep afloat after being torpedoed amidships. The internal subdivision of ships has long occupied the attention of naval constructors, and it is folly for any one unversed in all the details of naval and mercantile ship design to come forward with suggestions that show *à priori* the inventor's lack of understanding of the elements of that branch of applied science known as naval construction.

Military Airplane Photography. A. BROCK, JR. (*Aviation,* vol. ii, No. 8, p. 347, May 15, 1917.)—As early as 1850 Captain de Laussedat, of the French Engineer Corps, suggested the use of photography for surveying, and as a direct result of his work attempts were made to take photographs from captive balloons even prior to the Civil War. Although at that date the art of photography had not sufficiently advanced, nevertheless photographic surveying soon became a success, even with the wet-plate process, and with the introduction of the dry-plate the method was adopted by a number of governments. When military airplanes came into use the value of photography for correct location and delineation of objects was well understood.

The primary object of airplane photography is to obtain a complete and perfect record of that part of the terrain seen from an airplane; another object is to obtain a record in large enough scale to permit the recognition of most of the points of importance; while a third is to permit the placing of the various objects, as seen on the photographs, in their true location on the map. The employment of dummy guns, tree branches, paint, etc., to create a false impression was practically coincident with the development of airplane photography. One result of such photographs has been to change entirely the manner of placing field-guns. Now, a well-marked gun-pit does not necessarily denote the presence of a gun, as there may be found three or four well-marked gun-pits to each gun in actual use.

In the European war it has been found advantageous to obtain records from day to day of the holes made by high explosive shells which may be available for cover in carrying out attacks. This led to photographs large enough to permit of the closest possible identification in the negative or print. Until quite recently the average scale of military photographs was about 1/5000 actual size. Since this is the scale of a true horizontal photograph with a 12-inch lens at 5000 feet elevation, with the increased range of anti-aircraft guns, in some instances, lenses of extreme focal length were used. In practice, placing all enemy positions in their true location on the map has resulted in the location and destruction of field-guns a few hours after a photographic reconnaissance flight.

The Case-hardening of Iron by Boron. N. TSCHISCHEWSKY. (*The Mechanical Engineer*, vol. xxxix, No. 1007, p. 346, May 11, 1917; from *Proceedings of the Iron and Steel Institute*, May, 1917.)—On cooling iron-boron alloys, the boron is not wholly combined in the form of borides of iron, but a proportion of it is left in the form of a hard solution. This phenomenon suggests the possibility of case-hardening steel by boron similarly to the case-hardening of iron by carbon. Alloys of iron with boron are so remarkably hard that they can be scarcely attacked with an emery wheel. There is promise, therefore, in the technical application of case-hardening by boron of a feasible technical operation. The complete cementation that takes place in carbon steel is not the type of operation the author has in mind, but a surface cementation. It is more convenient to obtain a ferro-boric alloy by melting on account of the high price of boron, and also to secure its complete use without wastage. The use of boron is not perhaps suitable for armor plates, because of its comparative scarcity, but for some machine parts, and generally where much wear occurs, boron can be applied with success. No special heat treatment of articles hardened by boron is necessary, as is with articles case-hardened by carbon.

To ascertain the conditions of case-hardening by boron, cubes of soft iron were drilled in the centre to a depth of about half their length. These holes were filled with a fine amorphous boron or with powdered ferro-boron and the holes closed by iron plugs. In one experiment two samples were heated for two hours in an exhausted silicon tube at 950° C., one containing amorphous boron, the other powdered ferro-boron. Under the conditions of the experiment it was ascertained that cementation by powdered ferro-boron proceeds more easily and quickly than with amorphous boron. Microscopical examination shows that the hard white layer of the hardened part of the specimen consists of compact boric pearlite with a twin crystal structure. Case-hardening at a lower temperature yields an alloy of iron containing less boron. This alloy is not so hard and brittle as that described. In order to render the process suitable for industrial purposes it would be necessary to carry out a series of experiments on the conditions most suitable to the particular purpose in view.

Oxyacetylene Welded Versus Screwed Pipe Connections. ANON. (*Acetylene Journal,* vol. xviii, No. 11, p. 604, May, 1917.)—Supplementing tests made to determine the relative strength in tension and compression of oxyacetylene welded and screwed pipe connections, under the direction of Prof. F. H. Gibley, in the machine construction laboratory of the University of Kansas, reported in the March, 1916, issue of the *Acetylene Journal,* the same experimenters have completed tests on the strength of these connections when subjected to internal hydraulic pressure. The results of these tests bear out the conclusions given in the first series, namely: (*a*) The strength of the welded pipe connection is practically the same as that of unwelded pipe. By slightly building up the weld it can be made stronger than the rest of the pipe. (*b*) The strength of the welded pipe connection is much greater than that of malleable iron screwed fittings. (*c*) Although a careless or inexperienced operator may produce a leaky joint, nevertheless, if the pipe line is tested for leaks when installed, it should give no difficulty in service.

The pipe samples, which were cut from standard black steel pipe, were from the same stock and hence probably of uniform quality. Malleable iron couplings and ties were used for the screwed connections. The pieces for the butt welds were cut at an angle of about 60 degrees in a pipe-cutting machine to get the necessary "V" groove for welding. The "T" welds were made by cutting a hole in the run and butting the outlet against the run. The ends of all the specimens were sealed by welding in plugs or disks of boiler plate. Hydraulic pressure was supplied by means of a small pressure pump made for the work. Welded two- and three-inch specimens failed by splitting along the longitudinal seams of the pipe, the split stopping at the weld. A four-inch welded specimen bulged under the high pressure, but did not fail in either the weld or pipe seam. Two of the screwed connections failed by a tearing apart of the fitting at the thread. The bursting pressures of the screwed connections were far below those of the welded connections, and all failed in the fitting. Great difficulty was experienced in testing the specimens made up with screwed fittings because the leakage through sand holes made it almost impossible to reach the point of rupture. Only one case occurred in which there was failure at the weld, and that was merely a leak which did not develop until a pressure of 3850 pounds per square inch was applied.

Reducing Noise and Flash of Guns. N. FLAMEL. (*Scientific American Supplement,* vol. lxxxiii, No. 2158, p. 300, May 12, 1917. Translated from *La Nature.*)—To see unseen and to hear unheard are the two greatest factors of success in tactics and in strategy. Batteries no longer belch forth clouds of smoke to reveal their position. This we owe to Mr. Vieille, who was the first to achieve a really stable powder. Nowadays, smoke plays a part in war only to form a momentary mark or for signalling. Though it has been possible to suppress smoke by the use of powders that contain no mineral substances, or pure nitroglycerin, it has not been possible to suppress flame or flash. The Germans were the first to try to diminish flashes by adding to powders very small quantities of the salts of fixed alkalies or of the alkaline earth metals, such as the salts of calcium. They did not succeed. With cannon the flash always exists, though it may be diminished; but the moment the flame becomes less visible, smoke appears, and in the same measure that the flash diminishes in intensity the quantity of smoke is augmented; that is, the sum total of flame plus smoke remains constant. Nevertheless there has been some progress achieved, and the attenuation of the flame with a very light smoke is a satisfactory solution in the majority of cases. After nightfall the slightest flash reveals a gun, while smoke ceases to be visible and matters so little at night that black powders have often been used.

It is possible to arrive at a general solution of flash and noise by mechanical means, and it is essential to suppress noise as well as flash. These all resemble in general principle the familiar muffler used to silence the exhaust of the gas engine. In these devices the spent gases are diverted into a series of tortuous passages enclosed in a casing affixed to the muzzle in which they become cooled and lose much of their kinetic energy before escaping to the surrounding air. Numerous devices of this type have been designed and successfully used on rifles, but they do not appear to have been found applicable to the larger calibred ordnance. The Maxim silencer embodying this principle has been commercially produced in this country and exploited to a considerable extent for use with sporting rifles.

Automobile Storage Batteries. W. C. BROOKS. (*Proceedings of the American Electrochemical Society,* May 2–5, 1917.)—Following the invention of the pasted-plate type of lead storage battery in 1880 by Fauré in France and Brush in America, there has been no rival to this form of accumulator in portable service where high capacity per unit of weight is desired. It was therefore natural for this form of accumulator to develop into the present-day automobile storage battery. It has only one competitor, the nickel-iron cell, which, due to its high initial cost, internal resistance, and comparative bulkiness, is at present restricted to certain classes of industrial truck service. The nickel-iron cell is not used at all, to the writer's knowledge, in starting service in gasoline cars. No Planté or electrochemically formed pure lead plate batteries which are so familiar in central station and car lighting service are used on automobiles, on account of the low capacity per unit of weight and the difficulty of making a compact assembly, due to expansion of the positive plate in service. The automobile storage battery has therefore come to mean some compact, light form of pasted lead-plate element, generally in hard-rubber jars with thin wood separators. These cells are assembled into a battery with lead-alloy connectors and held in position by a hardwood case or tray.

There are three general divisions of service for automobile storage batteries: ignition, starting, and motive power. Ignition service is the first for which storage batteries were applied on gasoline cars. The discharge was extremely low, one-fourth to one ampère intermittently over a period of a month to a year. The batteries were charged at some service station whenever the user judged the battery to be exhausted. The storage battery proved fairly satisfactory for such service, but would have been displaced by the dry cell and magneto, had not the development of the high-efficiency tungsten lamps made possible electric lights. Then the storage battery became the only means to supply continuously the current for both lights and ignition. A few makers placed a generator on the engine to keep the battery charged.

The next development was the cranking motor. The cranking motor and the battery to run it solved the last major problem in popularizing the gasoline automobile. This service demands something entirely different from the battery. It not only has to furnish ignition for the engine, but current for several lights and energy up to one or two horsepower to start the engine. Thus the demand changed abruptly from a fraction of an ampère to several ampères continuously for lights and periodically 100 to 400 ampères for a few seconds, or even minutes, to crank the motor.

Electric vehicles were the first to use storage batteries, so it is in this service that the automobile battery has really developed, starting batteries being merely a modification of vehicle battery construction. This service demands for pleasure cars 60 to 80 volts and 25 to 50 ampères for four to six hours' continuous discharge. The discharge is intermittent, generally exhausting the battery about twice a week. Frequently, however, the battery is recharged before it is exhausted. The discharge rate is variable and batteries are often poorly cared for. Electric trucks require from 80 to 85 volts and 25 to 400 ampères, depending upon size of truck, grade of road, load, and speed. The heaviest current demand is on fire department ladder wagons, but the hardest service is on heavy trucks making long hauls which exhaust the battery daily.

Gravity Batteries of Low Local Action. Anon. (*Revue Scientifique,* vol. 55, No. 7, p. 208, March 24–31, April 7, 1917.)—The depolarization of primary batteries by means of oxygen in the air has often been attempted without much success. Oxygen, which is the depolarizer *par excellence,* available in the air in unlimited quantities and readily soluble in water, is apparently a most direct means to this end. The principal reason for the inefficacy of air as a depolarizer is that in all batteries the zinc electrode occupies the full height of the jar. It is easily understood that the small quantity of oxygen which dissolves at the surface attacks the zinc and, being thus combined, is evidently useless as a depolarizer. Another disadvantage of this local action of the oxygen on the zinc is that the electrode is rapidly worn away at the surface of the liquid, with a consequent loss in efficiency. These effects are particularly emphasized in open-circuit batteries. An obvious remedy is to arrange the zinc element at the bottom of the jar with the lower part of the carbon brought as near to it as possible to reduce internal resistance.

To verify this hypothesis Mr. Ch. Fery constructed a cell (*Société Française de Physique,* January 16, 1917) consisting of a sheet of zinc 45 millimetres square, provided with an insulating winding of twine in cross form. Upon this rested a carbon cylinder 32 millimetres outside diameter. The battery contained 150 c.c. of an eight per cent. solution of ammonium chloride. This element was discharged through a resistance of 80 ohms for 42 days. The formation of zinc chloride should have yielded six ampère-hours, while the actual yield was nine ampère-hours, showing that the action of oxygen from the air not only depolarizes, but also contributes to the consumption of the zinc. At the beginning of the discharge the voltage was 0.87 volt; at the end, 0.52 volt. Crystals of ammonium-zinc oxychloride of zinc are formed at mid-point on the carbon, but at neither the top nor bottom. Depolarization takes place very rapidly as soon as action ceases on opening the circuit. This action is readily explained. The lower end of the carbon near the zinc is strongly polarized, while the upper part in contact with the air is not polarized. When the circuit is opened, currents are formed between the two extremities of the positive electrode, which operates like a gas battery on short circuit. A large element which discharged for seven months through a resistance of 100 ohms delivered 43.75 ampère-hours with a consumption of 1.24 grammes of zinc per ampère-hour; the theoretical consumption is 1.228 grammes.

The Modern Automobile Torpedo. E. F. CHANDLER. (*Scientific American,* vol. cxvi, No. 22, p. 548, June 2, 1917.)—It was the submarine that really brought out the full possibilities of torpedo attack, simply because of its ability to make its way within easy range without exposing itself to gunfire. The tactical possibilities of the submarine have led to the development of a torpedo especially adapted for submarine use—a short-range weapon carrying a charge of about 400 pounds of explosive, which is 30 or 35 greater than that which fills the warhead of the standard torpedo. This end has been attained by employing weight and space previously given up to the propelling medium not needed when operating at such short ranges as 300 or 600 yards at which the submarine strikes.

The earliest torpedo was merely a tapered wooden spar, capped with an explosive head and capable of being projected over short distances. It soon gave way to a shell containing a propelling system. But, in spite of its increased speed and superiority to the tapered wooden spar, this form of torpedo, with a range of about 500 yards, was far too erratic, even though brought to a high state of mechanical perfection. It was the introduction of the gyroscope that gave us the modern automobile torpedo in providing a means of accurately maintaining its course and permitting a nearly doubled effective range.

As is well known, the body of the torpedo consists of a spindle-like shell of circular cross-section, tapering towards the after end and provided at the forward end with an explosive charge arranged to explode on impact, and a pair of driving propellers and steering gear at the after end. The intermediate space is occupied by a compressed-air tank, engine for driving the propellers, and auxiliaries. The early torpedo was driven by compressed air stored in the tank at 2000 pounds per square inch, driving a three-cylinder reciprocating engine at a pressure of 200 pounds per square inch, controlled by a reducing valve. In order to increase the range of the weapon, the air was heated by means of an alcohol flame at the exit orifice within the tank. The alcohol was ignited by a cartridge fired at the moment of discharge. This heating of the air had the additional advantage of eliminating freezing, which had always been a serious drawback when cold compressed air was used.

The modern torpedo, with a range of 5000 yards at 36 knots, is equipped with the same operating and controlling elements as the earlier type of weapon. The remarkable strides that have been made are due wholly to improvements in type and design of the component elements. For example, the air heater is now placed outside of the tank, and the engine is of the turbine type. In the earlier short-range torpedoes the gyroscope was spun by means of a spring which rotated the wheel at high speed by a sudden impulse. When the range was increased and it became necessary to store a greater amount of energy in the gyroscope during the short launching period of the torpedo—about a sixth of a second—it became apparent that a more powerful impulse was necessary. As a consequence the spring drive has been replaced by a small turbine driven by compressed air. By this device the efficiency of the gyroscope when released from connection with its driving mechanism retains its original plane of rotation, and any change in the course changes the relative position of the gyroscope's axis and adjacent structure. This angular movement is arranged to operate a compressed-air relay controlling the vertical rudders, and so any deviation from the course determined by the plane of rotation of the gyroscope is immediately corrected.

The torpedo is maintained in an even keel and at constant depth by the combined action of a fore-and-aft pendulum and a hydrostatic spring balance which control the compressed-air motor operating horizontal rudders. Any slight tilt changes the angular position of the pendulum, and any change in depth the hydrostatic pressure on the discharge, either of which immediately operates the horizontal rudder control. By this means the torpedo travels in a somewhat sinuous, though, on the whole, substantially straight, course, at a mean distance below the surface closely approximating the set depth. With this hydroplane control of the depth and level position, the torpedo may have either positive or negative buoyancy; that is, it may be arranged to either sink or float when not in motion. When the warhead or explosive charge is attached, it is arranged to sink when not in motion, but with a blank head for practice work it is arranged to float for easy recovery. The explosive charge is detonated by means of a firing pin and primer. Normally the pin is locked in the safety position by a nut; but when the torpedo is fired, the water causes a little propeller at the entrance point of the warhead to rotate and unscrew the nut, leaving the firing pin free to be pushed back when the torpedo strikes the side of the ship, thereby detonating the charge.

Replacing Steam Hammer with Electric Drive. ANON. *Electrical World,* vol. 69, No. 25, p. 1209, June 23, 1917.)—The Cumberland County Power and Light Company of Portland, Me., has recently been successful in the conversion of steam-hammer equipment to electro-pneumatic service, a pioneer installation being made at the plant of the Marine Hardware and Equipment Company. At this plant a 1200-pound Bement-Niles steam hammer was in service, steam at about 90 pounds per square inch being required for many hours daily. To avoid condensation troubles, it was necessary to run the hammer practically continuously. As electric-motor drive had been adopted for other purposes throughout the plant, it was found possible to do away with the demand for continuous high-pressure steam by adapting the steam hammer to air operation and installing a motor-driven compressor to supply air for this purpose and other requirements.

The valve of the steam hammer was rebuilt for a fit of 0.0025 inch compared with a previous fit of 0.005 inch under steam service. The Hardware company purchased a 50-horsepower, 220-volt, three-phase, Westinghouse squirrel-cage induction motor designed for 900 revolutions per minute, and belted it to a 12-inch by 7-inch by 12-inch Sullivan compressor delivering air at 90 pounds to the storage tank supplying the compressor. A branch exhaust terminating at two ½-inch pipes led down the frame of the hammer to outlets directed upon the working anvil surface, so that all chips and scale are immediately blown away in operation. It was found that harder and quicker blows could be struck than under steam conditions. Control of the hammer is obtained by a foot valve and lever.

Droop of Guns. J. W. BUNKLEY. (*United States Naval Institute Proceedings*, vol. 43, No. 172, p. 46, June, 1917.)—Droop may be defined as the bending of a gun due to the elasticity of the metal and to the imperfections in the manufacture of the gun. It may be expressed also as the angle that the final tangent of the curved bore makes with the axis of the gun at the breech. The subject of droop in guns has only lately received considerable attention, because it is only in recent designs that the length has been great enough to produce any appreciable bending. In guns of 12-inch calibre and larger the length of the bore forward of the trunnions has become so great that the bending can be detected by the unaided eye. In some cases the droop has been found to be more than one-half an inch. The deflection of the actual gun will never be less than this computed amount, but will be greater, according to the conditions of assemblage. The causes of droop of guns may be divided into three general heads, namely: Elasticity of metal; design of gun; imperfection in the manufacture of the gun.

A formula has been developed by Ordnance Engineer Jeansen for computing the deflection of heavy guns. This formula gives the deflection of droop of a gun caused by its own weight, considering the gun as a beam, irrespective of the system of assembling or locking the various pieces of the gun together. The depression of a gun is the theoretical bending of the elastic gun under ideal conditions. The flexure of a long gun, due to the unsupported weights in front of the cradle, is modified to a considerable extent by a general difference of temperature. The manufacturer of guns also plays an important part in the amount of droop.

[Considered as a solid elastic beam, the problem of finding the deflection of a gun does not differ from that of determining the deflection of a beam of variable cross-section occurring in structural design. A method possessing the merit of avoiding the need of such a formidable expression as derived by the author is given in *Engineering News*, vol. ii, page 340, 1907. It entails considerable labor in computation, but it does not require reference to special notes or formulas that cannot be easily remembered. This method is also described in the latest edition of Johnston, Bryan and Turneaure's "Modern Framed Structures" and elsewhere.—ED.]

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RADIATION AND THE ELECTRON.*

BY

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RECENT developments in the domain of radiation are of extraordinary interest and suggestiveness, but they lead into regions in which the physicist sees as yet but dimly—indeed, even more dimly than he thought he saw twenty years ago.

But while the beauty of a problem solved excites the admiration and yields a certain sort of satisfaction, it is after all the unsolved problem, the quest of the unknown, the struggle for the unattained, which is of most universal and most thrilling interest. I make no apologies, therefore, for presenting to-night one of the great unsolved problems of modern physics, nor for leaving it with but the vaguest of suggestions toward a solution.

The newest of the problems of physics is at the same time the oldest. For nothing is earlier in the experiences either of the child or of the race than the sensation of receiving light and heat from the sun. But how does light get to us from the sun and the stars through the empty interstellar spaces? The Greeks answered this query very simply and very satisfactorily from the standpoint of people who were content with plausible explanations but had not yet learned perpetually to question nature experimentally as to the validity or invalidity of a con-

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clusion. They said that the sun and all radiators of light and heat must shoot off minute corpuscles whose impact upon the eye or skin produces the sensations of light and warmth.

This corpuscular theory was the generally accepted one up to 1800 A.D. It was challenged, it is true, about 1680 by the Dutch physicist Huygens, who, starting with the observed phenomena of the transmission of water waves over the surface of a pond or of sound waves through the air, argued that light might be some vibratory disturbance transmitted by some medium which fills all interstellar space. He postulated the existence of such a medium, which was called the luminiferous or light-bearing ether.

Partly no doubt because of Newton's espousal of the corpuscular theory, the ether or wave theory gained few adherents until some facts of interference began to appear about 1800 which baffled explanation from the standpoint of the corpuscular theory, but which were easily handled by its rival. During the nineteenth century the evidence became stronger and stronger, until by its close the corpuscular theory had been permanently eliminated for four different reasons: (1) The facts of interference were not only found inexplicable in terms of it, but they were completely predicted by the wave theory. (2) The fact that the speed of propagation of light was experimentally found to be greater in air than in water was in accord with the demands of the ether theory, but directly contrary to the demands of the wave theory. (3) Wireless waves had appeared and had been shown to be just like light waves save for wave-length, and they had been found to pass over continuously, with increasing wave-length, into static electrical fields such as could not possibly be explained from a corpuscular point of view. (4) The speed of light had been shown to be independent of the speed of the source as demanded by the ether theory and denied by the corpuscular theory.

[illegible] ?

By 1900, then, the ether theory had become apparently impregnably intrenched. A couple of years later it met with some opposition of a rather ill-considered sort, as it seems to me, from a group of extreme advocates of the relativity theory, but this theory is now commonly regarded, I think, as having no bearing whatever upon the question of the existence or non-existence of a luminiferous ether. For such an ether was called into being solely for the sake of furnishing a carrier for electromagnetic waves, and it obviously stands or falls with the existence of such waves *in vacuo*, and this has never been questioned by anyone so far as I am aware.

Up to 1903, then, the theory which looked upon an electromagnetic wave as a disturbance which originated at some point in the ether at which an electric charge was undergoing a change in speed, and was propagated from that point outward as a spherical wave or pulse, the total energy of the disturbance being always spread uniformly over the wave front, had met with no serious question from any source. Indeed, it had been extraordinarily successful, not only in accounting for all the known facts, but in more than one instance in predicting new ones. The first difficulty appeared after the discovery of the electron and in connection with the relations of the electron to the absorption or emission of such electromagnetic waves. It was first pointed out in 1903 by Sir J. J. Thomson in his Silliman lectures at Yale. It may be stated thus:

X-rays unquestionably pass over, or past, all but an exceedingly minute fraction, say one in a thousand billion, of the atoms contained in the space traversed without spending any energy upon them or influencing them in any observable way. But here and there they find an atom from which, as is shown directly in C. T. R. Wilson's photographs here presented on the screen, they hurl a negative electron with enormous speed. This is the most interesting and most significant characteristic of X-rays, and one which distinguishes them from the α- and β-rays just as sharply as does the property of non-deviability in a magnetic field; for neither α- nor β-rays ever eject electrons from the atoms through which they pass with speeds comparable with those produced by X-rays, else there would be new zigzag lines branching out from points all along the paths of the α- and β-particles shown in the Wilson photographs.

But this property of X-rays introduces a serious difficulty into the ether theory. For if the electric intensity in the wave front of the X-ray is sufficient thus to hurl a corpuscle with huge energy from one particular atom, why does it not at least detach corpuscles from all of the atoms over which it passes?

Again when ultra-violet light falls on a metal it, too, like X-rays is found to eject negative electrons. This phenomenon of the emission of corpuscles under the influence of light is called the photo-electric effect. Lenard[1] first made the astonishing discovery that the energy of ejection of the corpuscle is altogether independent of the intensity of the light which causes the ejection, no matter whether this intensity is varied by varying the distance of the light or by introducing absorbing screens. I have myself[2] subjected this relation to a very precise test and found it to hold accurately. Furthermore, this sort of independence has also been established for the negative electrons emitted by both X- and γ-rays.

Facts of this sort are evidently difficult to account for on any sort of a spreading-wave theory. But it will be seen that they lend themselves to easy interpretation in terms of a corpuscular theory, for if the energy of an escaping electron comes from the absorption of a light-corpuscle, then the energy of emission of the ejected electron ought to be independent of the distance of the source, as it is found to be, and furthermore, corpuscular rays would hit but a very minute fraction of the atoms contained in the space traversed by them. This would explain, then, both the independence of the energy of emission upon intensity and the smallness of the number of atoms ionized.

In view, however, of the four sets of facts mentioned above, Thomson found it altogether impossible to go back to the old and exploded form of corpuscular theory for an explanation of the new facts as to the emission of electrons under the influence of ether waves. He accordingly attempted to reconcile these troublesome new facts with the wave theory by assuming a fibrous structure in the ether and picturing all electromagnetic energy as traveling along Faraday lines of force conceived of as actual strings extending through all space. Although this concept, which we shall call the ether-string theory, is like the corpuscular theory in that the energy, after it leaves the emitting body, remains localized in space, and, when absorbed, is absorbed as a whole, yet it is after all essentially an ether theory. For in it the speed of propagation is determined by the properties of the medium and has nothing to do with the nature or condition of the source. Thus the last three of the fatal objections to a corpuscular theory are not here encountered. As to the first one, no one has yet shown that Thomson's suggestion is reconcilable with the facts of interference, though so far as I know, neither has its irreconcilability been as yet absolutely demonstrated.

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[1] *Ann. d. Phys.* (4), viii (1902), 149.

[2] *Phys. Rev.*, ii (1913), 173.

But interference aside, all is not simple and easy for Thomson's theory. For one encounters serious difficulties when he attempts to visualize the universe as an infinite cobweb whose threads never become tangled or broken however swiftly the electrical charges to which they are attached may be flying about.

Yet the boldness and the difficulties of Thomson's "ether-string" theory did not deter Einstein[3] in 1905 from making it even more radical. In order to connect up with some results to which Planck, of Berlin, had been led in studying the facts of black-body radiation, Einstein assumed that the energy emitted by any radiator not only kept together in bunches or quanta as it traveled through space, as Thomson had assumed it to do, but that a given source could emit and absorb radiant energy only in units which are all exactly equal to $h\nu$, ν being the natural frequency of the emitter and h a constant which is the same for all emitters.

I shall not attempt to present the basis for such an assumption, for, as a matter of fact, it had almost none at the time. But whatever its basis, it enabled Einstein to predict at once that the energy of emission of corpuscles under the influence of light would be governed by the equation

$$\tfrac{1}{2}mv^2 = Ve = h\nu - p \quad \dots\dots\dots\dots\dots (41)$$

in which $h\nu$ is the energy absorbed by the electron from the light wave or light quantum, for according to the assumption it was the whole energy contained in that quantum, p is the work necessary to get the electron out of the metal, and $\tfrac{1}{2}mv^2$ is the energy with which it leaves the surface—an energy evidently measured by the product of its charge e by the potential difference V against which it is just able to drive itself before being brought to rest.

At the time at which it was made this prediction was as bold as the hypothesis which suggested it, for at that time there were available no experiments whatever for determining anything about how the positive potential V necessary to apply to the illuminated electrode to stop the discharge of negative electrons from it under the influence of monochromatic light varied with the frequency ν of the light, or whether the quantity h to which Planck had already assigned a numerical value appeared at all in connection with photo-electric discharge. We are confronted, however, by the astonishing situation that after ten years of work at the Ryerson Laboratory and elsewhere in the discharge of electrons by light this equation of Einstein's seems to us to predict accurately all of the facts which have been observed.

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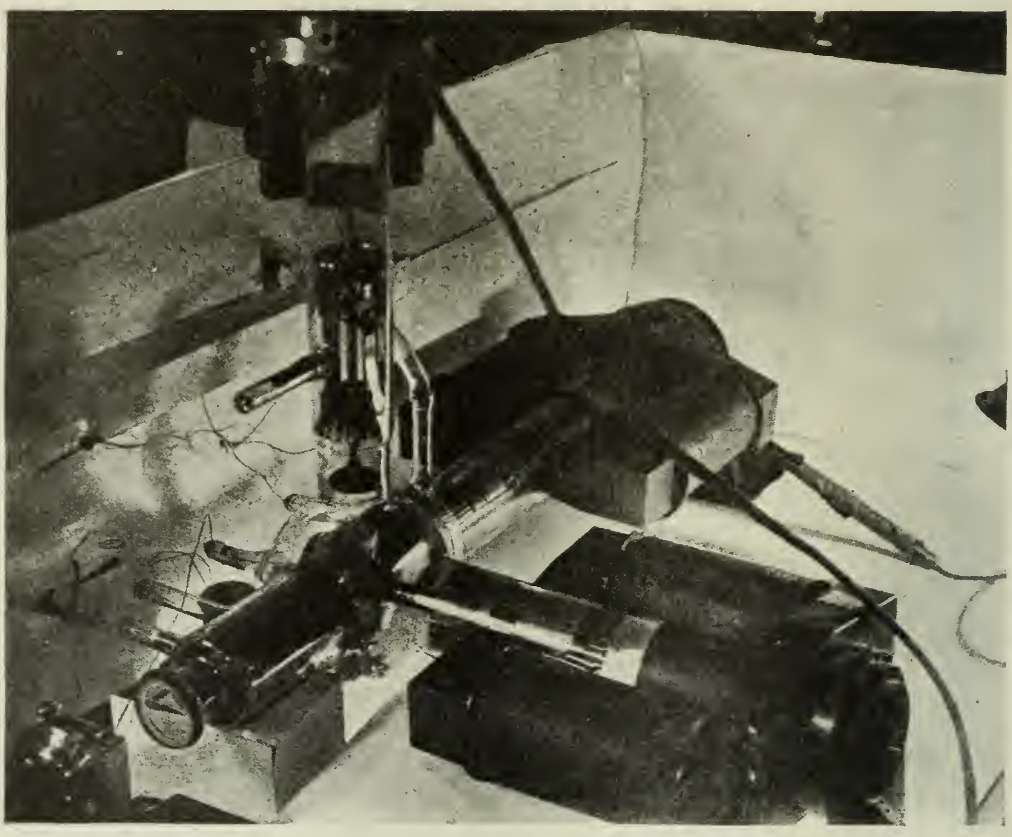
[3] *Ann. d. Phys.* (4), xvii (1905), 132; xx (1906), 199.

FIG. 1.

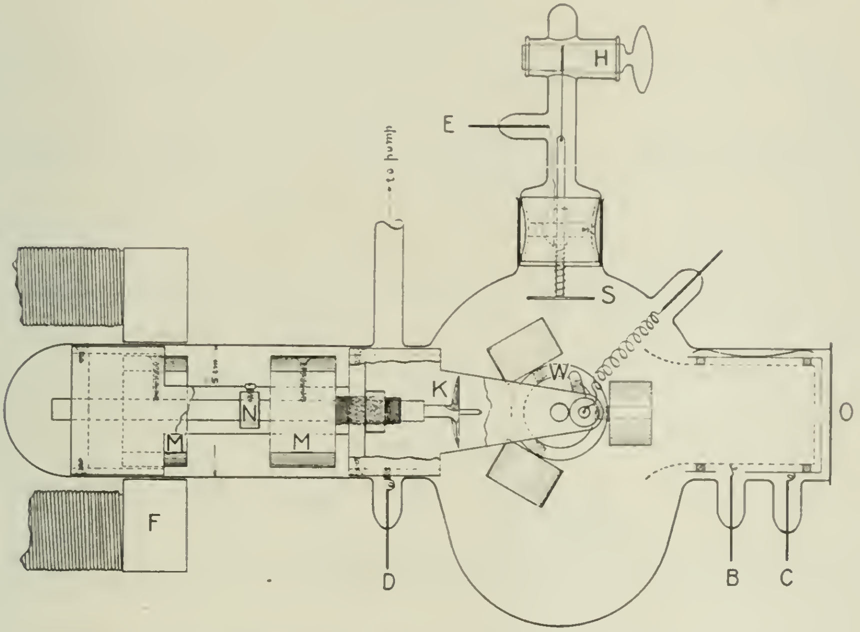


Photograph of apparatus used for the photo-electric determination of Planck's h.

The method which has been adopted in the Ryerson Laboratory for testing the correctness of Einstein's equation has involved the performance of so many operations upon the highly inflammable alkali metals in a vessel which was freed from the presence of all gases that it is not inappropriate to describe the present experimental arrangement as a machine-shop *in vacuo*. Fig. 1 shows a photograph of the apparatus, and Fig. 2 is a drawing of a section which should make the necessary operations intelligible.

One of the most vital assertions made in Einstein's theory is that the kinetic energy with which monochromatic light ejects electrons from any metal is proportional to the frequency of the light, *i.e.*, if violet light is of half the wave-length of red light, then the violet light should throw out the electron with twice the energy imparted to it by the red light. In order to test whether any such linear relation exists between the energy of the escaping electron and the light which throws it out it was necessary to use as wide a range of frequencies as possible. This made it necessary to use the alkali metals, sodium potassium, and lithium, for electrons are thrown from the ordinary metals only by ultra-violet light, while the alkali metals respond in this way to any waves shorter than those of the red, that is, they respond throughout practically the whole visible spectrum as well as the ultra-violet spectrum. Cast cylinders of these metals were therefore placed on the wheel *W* (Fig. 2) and fresh clean surfaces were obtained by cutting shavings from each metal in an excellent vacuum with the aid of the knife *K*, which was operated by an electromagnet *F* outside the tube. After this the

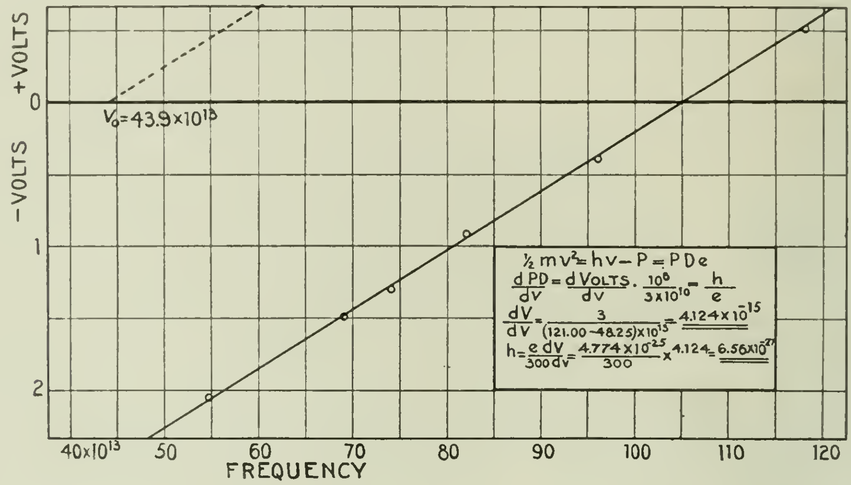
FIG. 2.



Cross-sectional drawing of apparatus of Fig. 1.

freshly cut surface was turned around by another electromagnet until it was opposite the point *O* of Fig. 2 and a beam of monochromatic light from a spectrometer was let in through *O* and allowed to fall on the new surface. The energy of the electrons ejected by it was measured by applying to the surface a positive potential just strong enough to prevent any of the discharged electrons from reaching the gauze cylinder opposite (shown in dotted lines) and thus communicating an observable negative charge to the quadrant electrometer which was attached to this gauze cylinder. For a complete test of the equation it was necessary also to measure the contact-electromotive force between the new surface and a test plate *S*. This was done by another electromagnetic device shown in Fig. 1, but for further details the original paper may be consulted.[4] Suffice it here to say that Einstein's equation demands a linear relation between the applied positive volts and the frequency of the light, and it also demands that the slope of this line should be exactly equal to $\frac{h}{e}$. Hence from this slope, since *e* is known, it be possible to obtain *h*. How perfect a linear relation is found may be seen from Fig. 3, which also shows that from the slope of this line *h* is found to be 6.26×10^{-27}, which is as close to the value obtained by Planck from the radiation laws as is to be expected from the accuracy

FIG. 3.



Graph showing relation between energy of electric emission and frequency of the light which stimulates the emission.

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[4] *Phys. Rev.*, vii (1916), 362.

with which the experiments in radiation can be made. The most reliable value of h obtained from a consideration of the whole of this work is

$$h = 6.56 \times 10^{-27}.$$

In the original paper will be found other tests of the Einstein equation, but the net result of all this work is to confirm in a very complete way the equation which Einstein first set up on the basis of his semi-corpuscular theory of radiant energy. And if this equation is of general validity it must certainly be regarded as one of the most fundamental and far-reaching of the equations of physics, and one which is destined to play in the future a scarcely less important rôle than Maxwell's equations have played in the past, for it must govern the transformation of all short-wave-length electromagnetic energy into heat energy.

In spite of the credentials which have just been presented for Einstein's equation, we are confronted with the extraordinary situation that the semi-corpuscular theory out of which Einstein got his equation seems to be wholly untenable and has in fact been pretty generally abandoned, though Sir J. J. Thomson[5] and a few others[6] seem still to adhere to some form of ether-string theory, that is, to some form of theory in which the energy remains localized in space instead of spreading over the entire wave front.

Two very potent objections, however, may be urged against all forms of ether-string theory of which Einstein's is a particular modification. The first is that no one has ever yet been able to show that such a theory can predict any one of the facts of interference. The second is that there is direct positive evidence against the view that the ether possesses a fibrous structure. For if a static electrical field has a fibrous structure, as postulated by any form of ether-string theory, "each unit of positive electricity being the origin and each unit of negative electricity the termination of a Faraday tube,"[7] then the force acting on one single electron between the plates of an air condenser cannot possibly vary *continuously* with the potential difference between the plates. Now in the oil-drop experiments[8] we actually study the behavior in such an electric field of one single, isolated electron and we find, over the widest limits, exact proportionality between the field strength and the force acting on the electron as measured by the velocity with which the oil drop to which it is attached is dragged through the air.

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[5] *Proc. Phys. Soc. of London,* xxvii (December 15, 1914), 105.

[6] "Modern Electrical Theory," Cambridge, University Press, 1913. p. 248.

[7] J. J. Thomson, "Electricity and Matter," p. 9.

When we maintain the field constant and vary the charge on the drop, the granular structure of electricity is proved by the discontinuous changes in the velocity, but when we maintain the charge constant and vary the field the lack of discontinuous change in the velocity disproves the contention of a fibrous structure in the field, unless the assumption be made that there are an enormous number of ether strings ending in one electron. Such an assumption takes all the virtue out of an ether-string theory.

Despite then the apparently complete success of the Einstein equation, the physical theory of which it was designed to be the symbolic expression is found so untenable that Einstein himself, I believe, no longer holds to it, and we are in the position of having built a very perfect structure and then knocked out entirely the underpinning without causing the building to fall. It stands complete and apparently well tested, but without any visible means of support. These supports must obviously exist, and the most fascinating problem of modern physics is to find them. Experiment has outrun theory, or, better, guided by erroneous theory, it has discovered relationships which seem to be of the greatest interest and importance, but the reasons for them are as yet not at all understood.

It is possible, however, to go a certain distance toward a solution and to indicate some conditions which must be satisfied by the solution when it is found. For the energy $h\nu$ with which the electron is found by experiment to escape from the atom must have come either from the energy stored up inside of the atom or else from the light. There is no third possibility. Now the fact that the energy of emission is the same, whether the body from which it is emitted is held within an inch of the source, where the light is very intense, or a mile away, where it is very weak, would seem to indicate that the light simply pulls a trigger in the atom which itself furnishes all the energy with which the electron escapes, as was originally suggested by Lenard in 1902,[9] or else, if the light furnishes the energy, that light itself must consist of bundles of energy which keep together as they travel through space, as suggested in the Thomson-Einstein theory.

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[8] *Phys. Rev.*, ii (1913), 109.

Yet the fact that the energy of emission is directly proportional to the frequency v of the incident light spoils Lenard's form of trigger theory, since, if the atom furnishes the energy, it ought to make no difference what kind of a wave-length pulls the trigger, while it ought to make a difference what kind of a gun, that is, what kind of an atom, is shot off. But both of these expectations are the exact opposite of the observed facts. *The energy of the escaping corpuscle must come then, in some way or other, from the incident light.*

When, however, we attempt to compute on the basis of a spreading-wave theory how much energy a corpuscle can receive from a given source of light, we find it difficult to find anything more than a very minute fraction of the amount which the corpuscle actually acquires.

Thus, the total luminous energy falling per second from a standard candle on a square centimeter at a distance of 3 m. is 1 erg.[10] Hence the amount falling per second on a body of the size of an atom, *i.e.*, of cross-section 10^{-15} cm., is 10^{-15} ergs, but the energy hv with which a corpuscle is ejected by light of wave-length 500 $\mu\mu$ (millionths millimeter) is 4×10^{-12} ergs, or 4,000 times as much. Since not a third of the incident energy is in wave-lengths shorter than 500 $\mu\mu$, a surface of sodium or lithium which is sensitive up to 500 $\mu\mu$ should require, even if all this energy were in one wave-length, which it is not, at least 12,000 seconds or 4 hours of illumination by a candle 3 m. away before any of its atoms could have received, all told, enough energy to discharge a corpuscle. Yet the corpuscle is observed to shoot out the instant the light is turned on. It is true that Lord Rayleigh has recently shown [11] that an atom may conceivably absorb wave-energy from a region of the order of magnitude of the square of a wave-length of the incident light rather than of the order of its own cross-section. This in no way weakens, however, the cogency of the type of argument just presented, for it is only necessary to apply the same sort of analysis to the case of γ-rays, the wave-length of which is of the order of magnitude of an atomic diameter (10^{-8} cm.) and the difficulty is found still more pronounced. Thus Rutherford[12] estimates that the total γ-ray energy radiated per second by one gramme of radium cannot possibly be more than 4.7×10^4 ergs. Hence at a distance of 100 meters, where the γ-rays from a gramme of radium would be easily detectable, the total γ-ray energy falling per second on a square millimeter of surface, the area of which is ten-thousand billion times greater than that either of an atom or of a disk whose radius is a wave-length, would be $4.7 \times 10^4 \div 4\pi \times 10^{10} = 4 \times 10^{-7}$ ergs. This is very close to the energy with which β-rays are actually observed to be ejected by these γ-rays, the velocity of ejection being about nine-tenths that of light. Although, then, it should take ten thousand billion seconds for the atom to gather in this much energy from the γ-rays, on the basis of classical theory, the β-ray is observed to be ejected with this energy as soon as the radium is put in place. This shows that if we are going to abandon the Thomson-Einstein hypothesis of localized energy, which is, of course, competent to satisfy these energy relations, there is no alternative but to assume that at some previous time the corpuscle had absorbed and stored up from light of this or other wave-length enough energy so that it needed but a minute addition at the time of the experiment to be able to be ejected from the atom with the energy $h\nu$.

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[9] *Ann. d. Phys.* (4), viii (1902), 149.

[10] Drude, "Lehrbuch der Optik," 1906, p. 472.

[11] *Phil. Mag.*, xxxii (1916), 188.

Now the corpuscle which is thus ejected by the light cannot possibly be one of the free corpuscles of the metal, for such a corpuscle, when set in motion within a metal, constitutes an electric current, and we know that such a current at once dissipates its energy into heat. In other words, a *free* corpuscle can have no mechanism for storing up energy and then *jerking* itself up "by its boot straps" until it has the huge speed of emission observed.

The ejected corpuscle must then have come *from the inside of the atom,* in which case it is necessary to assume, if the Thomson-Einstein theory is rejected, that within the atom there exists some mechanism which will permit a corpuscle continually to absorb and load itself up with energy of a given frequency until a value at least as large as $h\nu$ is reached. What sort of a mechanism this is we have at present no idea. Further, if the absorption is due to resonance—and we have as yet no other way in which to conceive it—it is difficult to see how there can be, in the atoms of a solid body, corpuscles having all kinds of natural frequencies so that some are always found to absorb and ultimately be rejected by impressed light of any particular frequency. But apart from these difficulties, the thing itself is impossible if these absorbing corpuscles, when not exposed to radiation, are emitting any energy at all; for if they did so, they would in time lose all their store and we should be able, by keeping bodies in the dark, to put them into a condition in which they should show no emission of corpuscles whatever until after hours or years of illumination with a given wave-length. Since this is contrary to experiment, we are forced, even when we discard the Thomson-Einstein theory of localized energy, to postulate electronic absorbers which, during the process of absorbing, do not radiate at all until the absorbed energy has reached a certain critical value when explosive emission occurs.

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[12] "Radioactive Substances and their Radiations," p. 288.

However, then, we may interpret the phenomenon of the emission of corpuscles under the influence of ether waves, whether upon the basis of the Thomson-Einstein assumption of bundles of localized energy traveling through the ether, or upon the basis of a peculiar property of the inside of an atom which enables it to absorb continuously incident energy and emit only explosively, *the observed characteristics of the effect seem to furnish proof that the emission of energy by an atom is a discontinuous or explosive process.* This was the fundamental assumption of Planck's so-called quantum theory of radiation. The Thomson-Einstein theory makes both the absorption and the emission sudden or explosive, while the loading theory, first suggested by Planck, though from another view-point, makes the absorption continuous and only the emission explosive.

The h determined above with not more than one-half of 1 per cent. of uncertainty is the explosive constant, *i.e.*, it is the unchanging ratio between the energy of emission and the frequency of the incident light. It is a constant the existence of which was first discovered by Planck by an analysis of the facts of black-body radiation, though the physical assumptions underlying Planck's analysis do not seem to be longer tenable. For the American physicists Duane and Hunt[13] and Hull[14] have recently shown that the same quantity h appears in connection with the impact of corpuscles against any kind of a target, the observation here being that the highest frequency in the general or white-light X-radiation emitted when corpuscles impinge upon a target is found by dividing the kinetic energy of the impinging corpuscle by h. Since black-body radiation is presumably due to the impact of the *free* corpuscles within a metal upon the atoms, it is probable that the appearance of h in black-body radiation and in general X-radiation is due to the same cause, so that, contrary to Planck's assumption, there need not be, in either of these cases, any coincidence between natural and impressed periods at all. The $h\nu$ which here appears is not a characteristic of the atom, but merely a property of the ether pulse which is generated by the stopping of a moving electron. Why this ether pulse should be resolvable into a continuous, or white-light spectrum which, however, has the peculiar property of being chopped off sharply at a particular limiting frequency given by $h\nu = PD \times e$ is thus far a complete mystery. All that we can say is that experiment seems to demand a sufficient modification of the ether-pulse theory of white-light and of general X-radiation to take this experimental fact into account.

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[13] *Phys. Rev.*, vi (1915), 166.

[14] *Ibid.*, vii (1916), 157.

On the other hand, the appearance of h in connection with the absorption and emission of *monochromatic* light (photo-electric effect and Bohr atom) seem to demand some hitherto unknown type of absorbing and emitting mechanism within the atom. This demand is strikingly emphasized by the remarkable absorbing property of matter for X-rays, discovered by Barkla[15] and beautifully exhibited in De Broglie's photographs here shown.[16] It will be seen from these photographs that *the atoms of each particular substance transmit the general X-radiation up to a certain critical frequency and then absorb all radiations of higher frequency than this critical value.* The extraordinary significance of this discovery lies in the fact that it indicates that there is a type of absorption which is not due either to resonance or to free electrons. But these are the only types of absorption which are recognized in the structure of modern optics. We have as yet no way of conceiving of this new type of absorption in terms of a mechanical model.

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[15] *Phil. Mag.*, xvii (1909), 749.

[16] These photographs will be found also in the August number of the *Physical Review* (see Presidential address of the President of the Physical Society).

There is one result, however, which seems to be definitely established by all of this experimental work. Whether the radiation is produced by the stopping of a free electron as in Duane and Hunt's experiment, and presumably also in black-body experiments or by the absorption and re-emission of energy by bound electrons, as in photo-electric and spectroscopic work, Planck's h seems to be always tied up in some way with the emission and absorption of energy by the electron. *h may, therefore, be considered as one of the properties of the electron.*

The new facts in the field of radiation which have been discovered through the study of the properties of the electron seem, then, to require in any case a very fundamental revision or extension of classical theories of absorption and emission of radiant energy. The Thomson-Einstein theory throws the whole burden of accounting for the new facts upon the unknown nature of the ether and makes radical assumptions about its structure. The loading theory leaves the ether as it was and puts the burden of an explanation upon the unknown conditions and laws which exist inside the atom. I have already given reasons for discrediting the first type of theory. The second type, though as yet very incomplete, seems to me to be the only possible one, and it has already met with some notable successes, as in the case of the Bohr atom. Yet the theory is at present woefully incomplete and hazy. About all that we can say now is that we seem to be driven by newly discovered relations in the field of radiation either to the Thomson-Einstein semi-corpuscular theory, or else to a theory which is equally subversive of the established order of things in physics. For either one of these alternatives brings us to a very revolutionary quantum theory of radiation, that is, a theory which calls for an explosive emission of energy in units and which therefore has something akin to atomism about it. To be living in a period which faces such a complete reconstruction of our notions as to the way in which ether waves are absorbed and emitted by matter is an inspiring prospect. The atomic and electronic worlds have revealed themselves with beautiful definiteness and wonderful consistency to the eye of the modern physicist, but their relation to the world of ether waves is still to him a profound mystery for which the coming generation has the incomparable opportunity of finding a solution.

The Grinding Wheel. R. G. WILLIAMS. (*Proceedings of the American Electrochemical Society*, May 2–5, 1917.)—The success of the modern grinding wheel is dependent to a very large degree upon the product of the electric furnace (namely, artificial abrasives), these having almost entirely supplanted the formerly widely used emery. Artificial abrasives are of two kinds or groups—the aluminous group and the carbide of silicon group. The first contains aluminum oxide as the main constituent, and the different materials which it forms vary quite widely in physical properties, according to their chemical composition and electric furnace treatment. The carbide of silicon abrasives, forming the second group, vary but slightly in chemical composition and physical properties.

The crude abrasive is delivered from the electric furnace to the grinding-wheel factory, and broken up into lumps which will pass through a six-inch ring and smaller. The first step in the production of grain to be used in grinding wheels and other products such as oilstones, rubbing bricks, refractories, and so forth, is to pass the material through powerful crushers equipped with manganese steel jaws. This operation reduces the material to small lumps. It is further reduced from small lumps to grains by passing through a series of rolls, each pair being set to crush smaller than the preceding. In this way a range of sizes from very coarse to very fine is produced. Some abrasives contain an appreciable amount of magnetic material detrimental to the manufacture of wheels. This is removed by means of a magnetic separator. The material is further freed from extraneous matter by a washing process. The material is then sized by passing through screens of varying mesh, and, for the very fine sizes referred to as "flour," by a sedimentation process.

All grinding wheels are composed of two main constituents—the abrasive and the bond, or the substance by which the particles of abrasive are held together. The commercial method of classifying grinding wheels is by the kind of bonding material used. The most widely used type of wheel is that bonded by a ceramic process in which the mixture of abrasive and a clay bond are baked in a kiln like pottery ware. Such wheels are known as *vitrified wheels*. Another type of bonding where elasticity is sought is represented by *vulcanized wheels*. Here, as indicated by the name, the bonding material is vulcanized rubber. The operation of vulcanizing the mixture of abrasive rubber and sulphur is similar to that employed in vulcanizing any other product. The wheels, which have been moulded approximately to size, are finally provided with a lead centre and trued to size with a diamond tool.

THE CHEMISTRY OF CELLULOSE AND ITS IMPORTANT INDUSTRIAL APPLICATIONS.*

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THE mere mention of the word "Cellulose" conveys to the average person very little meaning or significance, and yet cellulose, in one form or another, is just as essential to the convenience and comfort of modern humanity as are iron, copper, glass, and materials of this general type with which everybody is familiar. Cellulose may be defined as the material of which the cell walls of plants are composed, and consequently it is easy to appreciate the abundance of this substance in nature, and its wide dissemination over the face of the earth. Cellulose is a true carbohydrate, and in its simplest form is familiar to everybody in the shape of cotton, linen, or wood-pulp. Clean cotton is practically pure cellulose, but most cellulose in nature is in a compound form—lignocellulose—in which the cellulose is more or less strongly combined with lignin. From such lignocellulose it is not a matter of great difficulty, by digesting or cooking with proper chemicals, to isolate the cellulose. On this, of course, are based the wood-pulp and paper industries.

It is not the purpose of this lecture to go into intimate discussion of the absolute chemical composition of cellulose, or to consider from a theoretical point of view the chemistry of the various known reactions, but rather to deal with technical cellulose chemistry broadly, and perhaps bring out some points which are of interest to the user of cellulose products.

To date the true chemical structure of cellulose is not known. Several formulæ have been suggested, but they are all matters of speculation, because there are not sufficient data on which to base any definite structural formula. As has been stated, cellulose is a carbohydrate of the empirical formula $C_6H_{10}O_5$, but the cellulose molecule is very complex and made up of a large aggregate of groups of the composition designated by this formula. On account of the abundance of cellulose in nature, its synthesis offers very little inducement with the object of commercial substitution of an artificial cellulose, but there is no question that the ability to synthesize cellulose and the knowledge of its structural formula would be helpful both to pure science and to industrial applications of cellulose, for these reasons at least:

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1. It would increase our knowledge of nature's processes.
2. It would afford a better comprehension of the known cellulose reactions, and would be helpful in the elucidation of their eccentricities, of which there are certainly plenty.
3. It would greatly increase the possibilities of new cellulose reactions, and in this connection it should be stated that practically every known reaction of cellulose has become the basis of important processes.
4. It would also give us a more precise knowledge of what takes place in the dyeing of cellulosic fibres, and there are probably other advantages to be gained.

CELLULOSE SOLVENTS.

The solvents of cellulose—and in this connection do not confuse cellulose with cellulose compounds—are either very strongly acid or strongly alkaline in character. The discovery of a neutral solvent, the solution of cellulose in which could be readily coagulated by some other neutral chemical, or at the most a chemical only mildly acid or alkaline, or the discovery of a neutral volatile solvent, on the evaporation of which a cellulose film or deposit would be formed, would be discoveries of tremendous importance and value. The ordinary industrial solvents of cellulose which at the same time do not transform it into compounds other than those formed by the addition of water are strong sulphuric acid, zinc chloride or bromide, neutral or acid, and cuprammonium solution, which is a strong solution of copper hydrate or carbonate in ammonia. There are several other solvents, such as ammonium sulphocyanate, etc., but at the present time they are of no appreciable commercial importance.

Sulphuric acid finds its chief industrial application as a cellulose solvent in the manufacture of parchment paper, although a recent patent has been issued for the adaptation of a sulphuric acid solution of cellulose at very low temperatures to the manufacture of films and filaments. In the ordinary process for parchmentizing paper, the paper is run through a strong sulphuric acid bath, with the proper conditions of concentration, temperature, and speed, so that merely the surface of the paper is gelatinized, which on subsequent dilution and washing is coagulated and remains fixed on the surface of the paper, giving to the parchment paper its familiar grease-proof quality.

The chief applications of zinc chloride as a solvent are the manufacture of incandescent lamp filaments and the production of vulcanized fibre. In the former case, cellulose is dissolved in zinc chloride solution of high concentration, and this solution is squirted into the alcohol, whereby it coagulates into the filaments, which are washed free from chemicals and dried. In view of the rapid strides which the tungsten filament is making, this use of zinc chloride cellulose solution is gradually becoming less important.

In the production of vulcanized fibre, the process is somewhat similar to the sulphuric acid parchmentizing process, but in this case special absorbent paper is run through a strong zinc chloride solution, and the fibres are superficially gelatinized by means of the solvent. When thick sheets of vulcanized fibre are desired, thin gelatinized sheets are wound around a mandrel or drum to the desired thickness, and cement themselves together. In this process, as in the parchmentizing process, it is absolutely essential to eliminate all the zinc chloride or the sulphuric acid, because otherwise the products would disintegrate on storing, or else they would be deficient in desired properties.

A solution of cellulose in cuprammonium solution is the basis of one of the processes for the manufacture of artificial silk. This process has been extensively operated in Europe, but a few sporadic attempts to operate in this country have not met with success. The solvent power of cuprammonium for cellulose at one time was applied in England in the manufacture of Willesden goods.

HYDROLYSIS AND HYDRATION.

When cellulose is dissolved and recovered from a solution by coagulation, the original fibrous structure is, naturally, always destroyed. In the coagulated products the cellulose is in a highly hydrated condition, and these products are various forms of hydrated cellulose. It is a matter of controversy whether a cellulose hydrate is cellulose in a form capable merely of mechanically holding a large amount of water, or whether this water, in part at least, is chemically combined with the cellulose. Perhaps the burden of the evidence is in favor of mechanical absorption, and not the chemical combination, for it is true that when a cellulose jell or hydrate is once dried it does not then have the capacity of absorbing as much water as it mechanically held before drying.

Besides cellulose hydrates, there is another form or combination of water and cellulose, called "hydrocellulose." This is a real hydrolyzed form of cellulose, and is produced when acids and alkalies act on cellulose, with the proper conditions of time and temperature, and not necessarily with accompanying solution, because hydrocellulose may still preserve the form of the original fibre. In hydrolyzed cellulose the amount of water combined is variable, depending upon the severity of the hydrolysis, the ultimate result of continued hydrolysis being the formation of dextrose, similarly as in the formation of dextrose from starch. It is highly probable that the hydrolysis of cellulose proceeds along lines closely analogous to the hydrolysis of starch, and that between dextrose and sugar various dextrines are intermediately formed.

Industrially, the hydrolysis of cellulose is of great importance. It is the basis of the carbonization process for separating cotton from wool, in which, as you know, shoddy is immersed in a sulphuric or hydrochloric acid solution, and on drying, with the acid still in it, the cotton is converted into brittle hydrocellulose which is dusted out, leaving the wool behind. The production of hydrocellulose is also an intermediate step in the carrying out of some cellulose reactions; for example, in some of the processes of manufacturing cellulose acetate, hydrocellulose is first formed, and the esterification or formation of the acetate takes place afterwards. Also, in the viscose reaction—and of both of these reactions I will speak about later—the sustained action of the caustic soda on wood-pulp tends to break down the cellulose structure with accompanying hydrolysis. The complete hydrolysis of cellulose to sugar is assuming considerable industrial importance in the manufacture of ethyl alcohol from sawdust or other cellulosic wastes. This is an established process of demonstrated merit, and it is not unreasonable to predict that it will ultimately be the solution of the motor fuel problem, particularly if it can be adapted—and there seems to be no fundamental reason why it cannot be—to the hydrolysis of wastes from perennial plant growths. Inasmuch as hydrocellulose is soluble in all the cellulose solvents, and can usually be recovered from these in the gelatinous condition, it can readily be seen that a hydrocellulose hydrate or a hydrated hydrocellulose is a possibility, and is in fact an actuality.

OXIDATION.

Cellulose is susceptible to oxidation with the formation of oxycellulose, and the formation of a cellulose peroxide has been reported. Oxycellulose always is produced when cotton or wood-pulp is subjected to overbleaching. The extent of formation of the oxycellulose can be ascertained by determining the copper number or capacity of the bleached cellulose to reduce Fehling's solution, and a limitation of the copper number is not infrequently inserted at the present time in specifications for bleached linters for nitrating purposes. The production of oxycellulose is not carried out for any commercial purpose, as the formation of oxycellulose, like hydrocellulose, is always coincidental with loss in strength of the cotton or other cellulosic fibre.

ESTERIFICATION.

Before I touch on the esters of cellulose, such as cellulose xanthate, cellulose nitrate, cellulose acetate, etc., reference will be made briefly to a new product which has been developed in the past few years, which is not an ester, but an ether of cellulose. Cellulose ethers are the invention of Professor Lillienfeld, and they are supposed to be, and presumably are, true ethers and not esters. The usual ester produced is the ethyl ester, and, according to the patent, it is formed by the action of di-ethyl sulphate on cellulose which has been subjected to a rather severe hydrolysis or hydration treatment. It is claimed for the ethers that, like simple ethers and not esters, they are not susceptible to saponification, and, as there is no acid radical in their make-up, they remain perfectly neutral and stable. I have not had an opportunity to investigate these ethers nor the claims of the patent, and in so far as I know, at the present time, the product is not being made to any extent in the United States. Here is a small sample of film made from cellulose ether, and this is all I have ever seen. This particular sample is a very excellent product. A review of the patents leads one to believe that the technical difficulties controlling this reaction must be very considerable, and as we look back on the development of cellulose esters we well realize that the trials and tribulations incident to placing on a commercial basis any new cellulose reaction product are almost enough to discourage new workers in the field.

Of the esters of cellulose, perhaps cellulose nitrate is the one with which everybody is familiar. As a mere reaction, the formation of cellulose nitrate is exceedingly simple, for it consists of merely immersing cotton in a mixture of strong nitric and sulphuric acids. When this process is carried out, depending on the composition of the acids, the time, the temperature, and the character of the material treated, cellulose nitrates of different compositions and workable characteristics are obtained.

Cellulose apparently contains three reactive hydroxyl groups, consequently the limit of esterification is the cellulose tri-ester; for example, cellulose tri-nitrate. As a matter of fact, pure cellulose tri-nitrate is never obtained in practice. The degree of nitration is usually appraised on the basis of the nitrogen content of the ester. Cellulose nitrates are of tremendous industrial importance, more so than ever at present, because cellulose nitrate is the basis of smokeless powder and gun-cotton. But it is also of great importance in the production of materials quite foreign to war purposes, such as the manufacture of celluloid, moving-picture films, artificial silk, artificial leather, and the like. Cellulose nitrate enters into the composition of all these mentioned materials, but for the different purposes cellulose nitrates of different nitrogen content are used; for example, the nitrate used in moving-picture films and celluloid has a nitrogen percentage of, we will say, roughly, 10½ to 11¼ per cent., whereas for varnish purposes it runs from 11½ to 11¾ or even 12 per cent., for powder purposes between 12 and 12½ per cent. approximately, and for gun-cotton purposes between 13 and 14 per cent. All of these nitrates are very rapidly combustible on account of the presence of the unstable oxidizing nitrate radicle, and, other things being equal, the degree of inflammability increases with the nitrogen content. Celluloid, smokeless powder, and gun-cotton all belong to the same family, and it is naturally rather a dangerous family to become too intimately acquainted with, unless you fully understand its disposition and temper.

With celluloid you are all familiar. It is a compound of camphor and cellulose nitrate of low nitration. These are combined into a dough by the use of a small proportion of common solvent, which after proper working and baking under pressure produces a cake of celluloid. The function of the camphor is to impart softness, but more particularly moulding quality, to the mixture. It seems as if every chemical in Beilstein has been patented or suggested as a commercial substitute for camphor in celluloid manufacture, but, after all has been said and done, camphor still remains the material *par excellence*, and the only one which is universally used. It is quite characteristic of cellulose compounds that some one material performs a certain function in their manipulation, and the result achieved thereby is very difficult to duplicate with any other material or combination. For example, in the manufacture of lacquers, leather, and cloth finishes from cellulose nitrates, amyl acetate has for many years been the prime solvent, and it has been difficult to assail its position. More progress is being made in replacing amyl acetate, however, than in the substitution of camphor in celluloid, for the price of amyl acetate, due to the war, has absolutely compelled the use of other solvents, and various other liquids, such as di-acetone alcohol, acetone oil, various purified ketone mixtures obtained from this, ethyl acetate and ethyl acetate-benzol mixtures, are now being extensively used. Along this same line of preferential use is the use of castor oil with cellulose nitrate in the manufacture of artificial leather, waterproof sheeting, etc. Nothing seems to take the place of it, although almost every other oil, natural and blown, has been tried. Cellulose nitrate seems to have the capacity of carrying a large quantity of castor oil without permitting it to spew out appreciably at moderately high temperatures or over a lapse of time, and castor oil also seems to have the capacity of keeping the coating flexible at low temperatures. Other oils, like oxidized linseed, blown rape, etc., are used for certain purposes, but they are all far less universally applied.

VISCOSE.

Nearly twenty-five years ago a new cellulose reaction was discovered by Cross in London, and for quite a number of years it created quite a furore, and great and universal application was claimed for it. I refer to viscose, or cellulose xanthate. Working along the lines of the formation of xanthates of simple alcohols, the adaptation of this reaction to cellulose was worked out. In the production of viscose, cellulose is first treated with a strong caustic soda solution, and there is formed what is termed "alkali cellulose," and this in a moist condition is treated with carbon disulphide, forming sodium cellulose xanthate, deep yellow in color, and pasty or not, depending upon the conditions of the reaction. This product is soluble in the excess caustic soda, forming a deep yellow-colored solution, which at moderately high temperatures quickly coagulates or reverts with the gradual formation of hydrated cellulose, or, even standing at normal temperatures for a considerable period, the same reversion will take place. The solution is also readily coagulated by acids and numerous salts.

Whereas back in 1900 the widest possibilities were claimed for viscose, as a matter of fact only two or three important applications have survived, but they are truly important, and in themselves are ample justification for the early enthusiasm. Undoubtedly you are all familiar with artificial silk, wood silk, or fibre silk, as it is variously called. You ought to be especially familiar with it here in Philadelphia, because, so far as the United States is concerned, it is practically a local industry, and many thousand pounds a week of viscose silk are turned out at the plant of the American Viscose Company at Marcus Hook. Besides silk, a large quantity of thin viscose film, 0.001 inch thick, is produced in France, and is sold in this country under various trade names, such as cellophane, which is used as a transparent protection over candy boxes, in wrapping candies, etc. Thicker films than this are not on the market at present, although I understand that considerable experimental work is being done to adapt viscose film to the photographic industry. I have here a sample of cellophane, also a sample of viscose silk, to which I will refer again later. You may also be interested in some of these various other viscose samples which represent, unfortunately, at the present time, only blasted hopes. (Samples of viscose sheets, viscoid, and viscose cloth prints were shown.)

CELLULOSE ACETATE.

We now come to a subject to which I have given considerable of my personal time for the past fifteen years, and therefore I hope I may be pardoned if I elaborate on it more extensively than has been done with the other reactions. Reference is being made to cellulose organic esters, which, so far as commercial products are concerned, mean cellulose acetate. Commercial cellulose acetate is tri-acetate and not tetracetate, and is made by reacting on cotton or rag paper with acetic anhydride and a suitable catalyst or condensing agent. Unfortunately, glacial acetic acid cannot substitute for the anhydride, although a recent foreign patent claims its use for this purpose. Our laboratory has not had time as yet to investigate this claim, but, judging from numerous experiments which have been made in our laboratory with this end in view, it seems exceedingly doubtful that cellulose acetate can be made without acetic anhydride.

Cellulose acetate is on the market in various forms, of somewhat different characteristics. It may look like cotton, as, for example, this sample of fibrous cellulose acetate which I have here, or it may be in a granular or powdered form, like this other sample. Purposely this large sample has been spread out on this table to emphasize its perfect harmlessness. Any one would hesitate to do the same thing with dry cellulose nitrate. In the production of the granular form, acetic anhydride acts on cellulose in the presence of usually a little sulphuric acid, and the reaction mixture is diluted with glacial acetic acid, and as fast as the cellulose acetate is formed it goes into solution, from which it is recovered by precipitation with water. In the production of the fibrous cellulose acetate the above reaction mixture is supplemented by the addition of a non-solvent of cellulose acetate, such as benzol or carbon tetrachloride. The esterification proceeds without solution of the cellulose acetate, which remains in essentially the original form of the cotton used, although very much more bulky and not so strong. By this process it is, of course, not difficult to acetylate cotton cloth, yarns, etc. Here is a sample of cellulose acetate cloth, and also a sample of the cheesecloth from which it was prepared. Both the fibrous process and the granular process are susceptible to certain modifications, so that products of different solubilities and different physical properties can be obtained. It also is possible to further change the solubilities of the products by subsequent treatment after the ester has been formed, and these treatments have been called hydrating the ester, although I am not prepared to say that this is a true designation of the transformation. The effect of such after-treatments is to increase the solubility of the cellulose acetate in various solvents, particularly in acetone, methyl acetate, alcohol-benzol mixtures, etc.

Up to the present time we have not succeeded in making a fibrous cellulose acetate of as great a range of solubility as it has been possible to obtain with the granular acetate, and it seems as if the wide range of solubility of the granular acetate necessitates a breakdown of the fibrous structure, with possibly some different arrangement within the molecule.

At this point it is perhaps well to refer to the question of viscosity in connection with cellulose products and solutions. Independent of the form or the solubility that the cellulose ester may take, it is possible to make products otherwise identical, but which dissolve in solvents forming for the same concentrations, solutions of entirely different viscosities. The explanation of this undoubtedly lies in the complex nature of the cellulose molecular aggregate: the higher the aggregation, the more viscous the solution, and *vice versa,* and the higher the aggregate the tougher is the film or filament which can be produced from the solution. This can be accepted as generally true.

A given product will not by any means produce solutions of the same viscosity with different solvents, for, with identical concentration, solutions of the same product in different solvents may cover a wide range of viscosity. In mixed solvents sometimes a very little of one component will have a very pronounced effect on the viscosity. For example, the viscosity of a solution of cellulose acetate in tetrachlorethane is tremendously reduced by the addition of either methyl or ethyl alcohol, and, similarly, a very viscous solution of cellulose nitrate, say, for example, in a mixture of amyl acetate and benzol, is very much reduced in viscosity by the addition of one or two per cent. of acetone. In the case of cellulose acetate, methyl or ethyl alcohol is a non-solvent of cellulose acetate, but in the case of the nitrate solution acetone is a very powerful solvent. These solubility peculiarities make a very interesting subject for research, and very little has been done along these lines to date.

The uses to which cellulose acetate is put are very numerous. In general they are essentially the same as those to which cellulose nitrate is adapted, with the single exception of the manufacture of explosives. In the non-inflammability and slow combustibility of cellulose acetate products really lies their excuse for commercial application, because they are invariably more expensive than nitrate products. Nowadays "Safety First" is the universal cry, and consequently, notwithstanding its cost, cellulose acetate is finding extensive application.

COMPARISON OF DIFFERENT TYPES OF CELLULOSE PRODUCTS.

Practically very little has been said or written about the comparative qualities and properties of different materials made out of different cellulose compounds, particularly viscose, cellulose nitrate, and cellulose acetate. Among the most important applications are the manufacture of lacquers and varnishes, coated fabrics, photographic and other films, artificial silk, etc., which will be discussed from the point of view of comparative use of the different cellulose compounds.

It is not uncommon for users of one cellulose compound to think that they can take another similar cellulose compound, dissolve it in the same solvents, compound it in the same way, and adapt it to the same uses as they have been accustomed to do with the compound with which they are most familiar. As a matter of fact, almost every cellulose compound has its different solvent requirements, different methods of compounding, and must be handled in its own special way to produce optimum results, and general substitution is not always possible. If people would recognize this and be a little more generous with information, their inquiries could be handled more intelligently and with much better prospect of working out their particular problem.

Lacquers.

For a great many years cellulose nitrate lacquers have held undisputed sway. Cellulose acetate lacquers have made relatively small inroads into this field, particularly on account of the high cost and the nature of the solvents which it has been necessary to use. However, a good many thousand gallons a year are used by a few concerns for lacquering certain brass parts of gas and electric fixtures which are subjected to a moderately high temperature. It has been found that a properly-compounded cellulose acetate lacquer gives a finish which stands up a great deal better for this particular use than does a nitrate lacquer and the very small difference in cost of the finished article is justified by the more durable protection.

Perhaps the oldest use of cellulose acetate in the United States is for insulating very fine copper wire. About seventeen years ago the General Electric Company standardized cellulose acetate insulations on their 0.003-inch wire used on their meter armatures. Previous to this standardization silk had been used as the insulating material, but it was very expensive and bulky, and the reduced space factor provided by the very fine cellulose acetate insulation was an important consideration. For making small meter armatures where there are a great many ends the cellulose acetate coating presented also another advantageous feature. The ends have to be soldered together, and to do this the insulation must be stripped, and the stripping of the cellulose acetate coating was very readily done. About two years ago this stripping was successfully accomplished on linseed oil enamelled wire, and the relatively low cost of the latter caused it finally to displace cellulose acetate for this particular purpose.

Varnishes.

At the present time the largest use of cellulose acetate in the United States is for the manufacture of varnishes, particularly airplane cloth varnishes. The business has naturally had tremendous stimulus since the war broke out, and perhaps only those people who are in close contact with it really realize how rapidly airplane manufacture is extending.

Airplane wings consist of a framework covered with unbleached linen, which must be made water-and-air-impervious and drumhead-tight. To accomplish this result, the linen is stretched tightly over the frame and is then varnished with cellulose varnish, which while drying causes powerful shrinkage in the fabric. This shrinkage at times has been known to be so great as to warp and break the frames, but this happens usually when the cloth is stretched too tightly before varnishing. Abroad only cellulose acetate is used as a shrinking varnish, but in this country both cellulose acetate and cellulose nitrate are used, sometimes alone, and sometimes cellulose nitrate is used as the impregnating coating, and then cellulose acetate varnish is used for the finish coating, the purpose of the latter being to make the wing spark- and flash-proof. Cellulose nitrate varnishes are not so expensive as cellulose acetate varnishes, and consequently some manufacturers let their judgment get the better of them, and standardize on the use of a cellulose nitrate varnish, notwithstanding that it introduces a latent risk, which at present they quite ignore. Undoubtedly they will think better of this when airplanes become more popular as a means of conveyance. Unquestionably the people will demand the elimination of every risk, although, judging by the automobile, who really can predict what the future airplane will look like, or how it will be constructed, and shrinking varnishes may not be used?

It has been suggested that some mention be made of what has been accomplished in the production of transparent wing coverings. Not so very many months ago there was a great deal of newspaper publicity about some airplanes which were made in Germany the wings of which were stated to be covered with a transparent, non-inflammable film which reduced the visibility. Very little has been heard about this lately, and all the meagre information I have ever obtained on this subject was secured from the newspaper and periodical reports and discussion with newspaper editors. Aside from what was disclosed in these publications, I have been able to obtain no information of the precise structure of this wing, except that it was composed of a cellulose acetate transparent film properly strengthened and supported.

In a lecture given in Boston in November by General Squier, which lecture was afterwards published in the JOURNAL OF THE FRANKLIN INSTITUTE of January, 1917, General Squier referred to the desirability of a transparent wing covering for airplanes, and his statement of the requirements of such a transparent covering I will repeat:

1. It must weigh not more than five ounces per square yard.
2. It should present reasonably great resistance to flame.
3. It should be reasonably proof against action of salt water, moist air, extreme dryness, and quick temperature changes.
4. It should not stretch in any direction. Its ability to retain its original form as placed on the airplane is very important.
5. It should have tensile strength of at least 75 pounds per inch width in any direction.

6. Its tendency to tear and split because of tack or bullet holes should be as small as possible.

Now these are mighty hard specifications to hit for any transparent materials known to-day. The ordinary linen used on airplanes weighs three and one-half to four ounces per square yard, and the weight of the coating is approximately two ounces per square yard, and, as there is a top and bottom layer of fabric on each wing, the cloth, plus coating, weighs about 10 to 12 ounces per square yard of wing surface.

A single sheet of cellulose acetate film 0.010 inch thick would weigh per square yard just about the same as the double layer of coated linen cloth. The film has a tensile strength per inch width of about 80 pounds, it is reasonably resistant to flame, is proof against salt water, although it has a very slight absorption of moisture, and when thoroughly seasoned there is very little stretch. Like all other films, however, it does have a tendency to tear and split because of tack holes, and the same would apply, of course, to bullet holes.

In order to overcome this, experiments are being made on a wire-mesh fabric filled with a cellulose acetate film, and a sample of such a fabric I have here. This particular sample is woven of bronze wire, weighs about 25 ounces per square yard, and has a tensile strength of about 100 pounds per inch width. A single layer of this fabric, therefore, weighs about twice as much as the present wing covering per square yard.

In order to lighten this mesh, some experiments have been made with a 12-mesh aluminum wire gauze made out of 0.016-inch wire. With the use of aluminum the finished weight per square yard has been reduced to 17 ounces, but even this is 50 per cent. more than the present wing covering or General Squier's specifications, assuming, when he stated that the transparent wing covering must weigh five ounces per square yard, that this means the single covering. At the present time we are endeavoring to get a more open mesh fabric with even finer wire, so as to give greater transparency and lightness. Assume, however, that the average total wing spread of an airplane is 500 square feet, or 55 square yards, then, even if the wing covering is 10 ounces per square yard heavier than the present covering, this increase would amount to only 35 pounds, which isn't even the difference in weight between a fat and a skinny aviator.

Artificial Leather and Leather Finishes.

The only cellulose product used for this purpose in the United States to any extent is a cellulose nitrate and castor oil combination. Cellulose acetate has not found any advantage for this purpose as yet, primarily because it will not blend satisfactorily with castor oil or any other oil. It is also too expensive, and its solvents are too expensive. Most of these artificial leather coatings are loaded with pigments which tend to reduce the inflammability of the cellulose nitrate. There is a distinct prejudice, which amounts almost to prohibition, against the use of a cellulose nitrate artificial leather in car curtains. At present these are coated with materials other than cellulose compounds. The use of artificial leather at the present day—and by this I mean particularly embossed coated cloth—is a very large business, millions of yards being annually produced, and it is really fortunate, with the decreasing leather supply, that such a substitute is available for many purposes. There is still a great deal of room for improvement in artificial leather products, because the present material is not adaptable as a substitute for upper leather on shoes. The coating is not sufficiently resistant to stand the necessary wear.

Films.

Viscose, cellulose nitrate, and cellulose acetate are all used in the production of films. As was previously stated, all the viscose on the market is in very thin sheets, approximately 0.001 inch thick, which are used for wrapping purposes, although experimenting is being carried out on thicker products for photographic purposes. Viscose has the disadvantage of not being nearly as waterproof as nitrate or acetate film; that is, it has a relatively high water absorptive capacity, which for some film uses is of no consequence, and for others is a decided detriment. Cellulose acetate has not displaced cellulose nitrate in this country for camera and cinematograph purposes. The reason for this is entirely commercial, and has no bearing on the intrinsic merit of cellulose acetate for this purpose. In France and Germany the use of non-inflammable cinematograph films is compulsory, and ultimately it will be in this country, although when this becomes the case it does not necessarily mean that the film will be cellulose acetate, for it might be viscose or a cellulose ether film. For various uses where the non-inflammable feature is of distinct advantage cellulose acetate films are gradually being substituted for celluloid films, and are finding adaptation where celluloid has never been used, and this in spite of the very much higher cost of the cellulose acetate film. Many thousands of goggles are produced every week of the non-inflammable film, and I have here a number of samples of various sizes and color combinations. For other forms of protective masks and helmets these films are also used, and the advantage of the non-inflammability, of course, is self-evident. Visible indexes or visible card systems are extending rapidly. A great deal of celluloid is used as a transparent covering in the manufacture of these indexes, and some of the largest concerns are wide awake to the great danger of the use of celluloid in connection with these valuable and difficultly replaceable records, and are demanding the substitution of a non-inflammable film for this purpose. A novel use of cellulose acetate film has been tried this winter near Boston. A street railway company found itself short of closed-car equipment, and was unable to secure new cars. It therefore made over some of its open cars into closed smoking cars by installing heaters and inserting cellulose acetate windows in the curtains.

There are numerous other places where the substitution of a waterproof, non-inflammable film seems to be desirable.

Cellulosic Filaments.

Perhaps the most fascinating application of cellulose compounds is in the manufacture of artificial silk, and incidentally coarse filaments as substitutes for horse-hair and artificial bristles. Recovered cellulose filaments are not particularly suitable for bristle purposes, because they distort so badly when wet. Cellulose nitrate is not adaptable on account of its high inflammability. This leaves cellulose acetate, then, as the most suitable compound, but even cellulose acetate bristles have a defect in common with the others; that is, they lack resiliency or life, and when sharply bent do not spring back to their original position. This is well illustrated in this hair-brush, which was made in England and arrived in the condition shown here. This brush is several years old, as well as this little clothes brush in which acetate bristles make up the body of the brush, but the outer edge is made up of natural bristles. This is still in excellent condition.

Unfortunately there is not sufficient time to discuss in great detail the various processes of manufacturing artificial silk and the differences in the products obtained. Briefly, however, there are four processes being operated at the present day—the Chardonnet or cellulose nitrate process, the Cuprammonium process, the Viscose process, and the Cellulose Acetate process. The final products of the first three processes are not chemically very dissimilar, as they are all straight recovered cellulose, or hydrated cellulose. It is true that the Chardonnet or cellulose nitrate process produces directly a filament composed of a cellulose ester, but this, of course, is so highly inflammable that the silk must go through a process of denitration to eliminate the nitrate radicle, leaving the silk ultimately as recovered cellulose. Of these three processes, the viscose process is the more recent and is making the most rapid strides, and bids fair to ultimately replace the other two. All these silks, however, have one very fundamental defect, and that is their great loss of strength when wet. The tensile strength will drop off 75 to 80 per cent. A process called the Sthenosage process was invented some time ago for treating artificial silk with formaldehyde and other chemicals for the purpose of increasing its strength when wet. In so far as I can learn, however, this process has not had extensive application, and I have been informed that the chief reason for this has been that it affects the dyeing properties of the silk, and the process is difficult to control.

The baby in the artificial silk field is cellulose acetate silk. Inasmuch as the acetyl radicle does not impart inflammability to the cellulose, it is not necessary to remove it, and as cellulose acetate is essentially waterproof, the silk is likewise so. Cellulose acetate silk is very much stronger wet than any other type of artificial silk. Whereas viscose silk, for example, will lose 75 to 80 per cent. of its tensile strength when wet, cellulose acetate will lose only 20 to 25 per cent. of this strength, and consequently, whereas the dry silks have about the same strength, the wet acetate silk has over three times the strength of wet viscose silk. Viscose in an atmosphere saturated with moisture at normal temperatures will pick up about 30 per cent. of its original weight of water, with proportionate decrease in strength, whereas acetate silk will pick up only about 6 per cent. of water, and the consequent decrease in strength is very little. The relative loss of strength of these two types of silk can be illustrated by this very simple experiment. The silk used in this test is 150 denier, and I will make a double loop of it and hang on it a 500-gramme weight, which it ought to readily support when dry. If this viscose silk now is moistened, the loss in strength is so great and rapid that the silk will no longer sustain this weight. If this same experiment be repeated with cellulose acetate silk, as can be readily seen, the strength of the silk, wet as well as dry, is entirely sufficient to carry the weight.

Chardonnet, Viscose, and Cuprammonium silks are all practically straight cellulose, and in their dyeing properties they are identical with cotton, although usually, on account of the treatment they have gone through, their affinity for the dyes is slightly greater. Cellulose acetate silk, however, being a cellulose compound, has quite different dyeing properties from the other artificial silks, and it has different dyeing properties than any other fibre, so that in this respect alone it constitutes a product of entirely new possibilities. Cellulose acetate silk of the type of this sample cannot be dyed with direct cotton colors nor with sulphur, acid, or vat colors unless the alkali used in the dyeing is of sufficient strength and the treatment sufficiently drastic to partially saponify the silk.

Those who are familiar with dyeing methods can readily see that the cross-dyeing possibilities of cellulose acetate silk unions are quite outside the range of those of any other artificial silk fibre. For example, it is possible to weave a fabric of cotton warp and acetate silk filling or pattern and dye the fabric with a direct cotton color, leaving the silk uncolored, or it is possible to dye the fabric with a basic color without mordant, thereby coloring the silk and leaving the cotton uncolored. The same can be done with an artificial silk union, part acetate silk and part viscose silk, and even in cotton, wool and cellulose acetate silk unions it is possible to color the cotton and the wool and leave the silk uncolored. Cellulose acetate silk is also a very good resist to logwood dyes, which is another distinct advantage. (You may be interested later in looking at these few samples of artificial silk which I have here—some acetate silk, and others viscose silk.)

PHYSICS OF THE AIR.*

BY

W. J. HUMPHREYS.

INEQUALITY OF SEASONAL TEMPERATURE CHANGE OF LOWER AND UPPER ATMOSPHERE.

As just explained, if T_2 is the absolute temperature of the black surface that gives off radiation equivalent to that sent out by the convective portion of the atmosphere and T_1 the absolute temperature of the isothermal region, then

$$T_1 = T_2 \sqrt[4]{2} = 0.84\ T_2, \text{ roughly.}$$

Hence the greater T_2, or the warmer the lower atmosphere, if its composition remains the same, the greater the difference between T_1 and T_2, or the greater the contrast between the temperature of the lower atmosphere and that of the isothermal region. This is in keeping with the observed fact (Fig. 15), that the seasonal difference in the temperature of the isothermal region, while in the same sense as that of the lower atmosphere, is not so great as is the latter. Because of seasonal differences in the composition of the lower atmosphere, especially in the average amount and distribution of water vapor, there can be no constant relation between the above temperature differences—only the qualitative relation as given.

HEIGHT OF THE ISOTHERMAL REGION.

If H_1 is the height and T_1 the temperature of the under surface of the isothermal region above the level H_0, whatever that may be, whose temperature is T_0, then

$$H_1 = H_0 + \int_{T_0}^{T_1} \frac{dH}{dT} dT$$

As above explained, the greater the temperature of the lower atmosphere, the greater the difference between this temperature and that of the isothermal region, or, in symbols, the greater T_0 the greater $T_0 - T_1$, and therefore the greater H_1. Hence the isothermal region should be at a greater elevation during summer than during winter. Another way of showing this same thing is as follows:

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* Continued from page 178, vol. 184, August, 1917.

Let the difference between the summer and winter temperatures of the lower atmosphere be ΔT_2 throughout, and the corresponding difference between the temperatures of the upper atmosphere ΔT_1, then, according to the above theory, $\Delta T_1 = 0.84\Delta T_2$, roughly. This, as already explained, is a radiation result. The inequality or $0.16\Delta T_2$ is produced by convection. Now if h is the change in elevation corresponding to 1° C., we have

$$\Delta H = 0.16\Delta T_2 h.$$

But, ΔT_2, winter to summer, is roughly 12° C., and h about 110 metres. Hence the change in the seasonal elevation of the isothermal region, if there is constancy in atmospheric composition, is, roughly,

$$\Delta H = 0.16 \times 12 \times 110 = 211.2 \text{ metres.}$$

It must be distinctly noted, however, that many disturbing elements, such as quantity and distribution of water vapor, frequency and extent of cirrus clouds, and the like, so modify these simple relations that they apply only to average conditions, and to them but approximately.

STORM EFFECTS ON TEMPERATURE GRADIENTS.

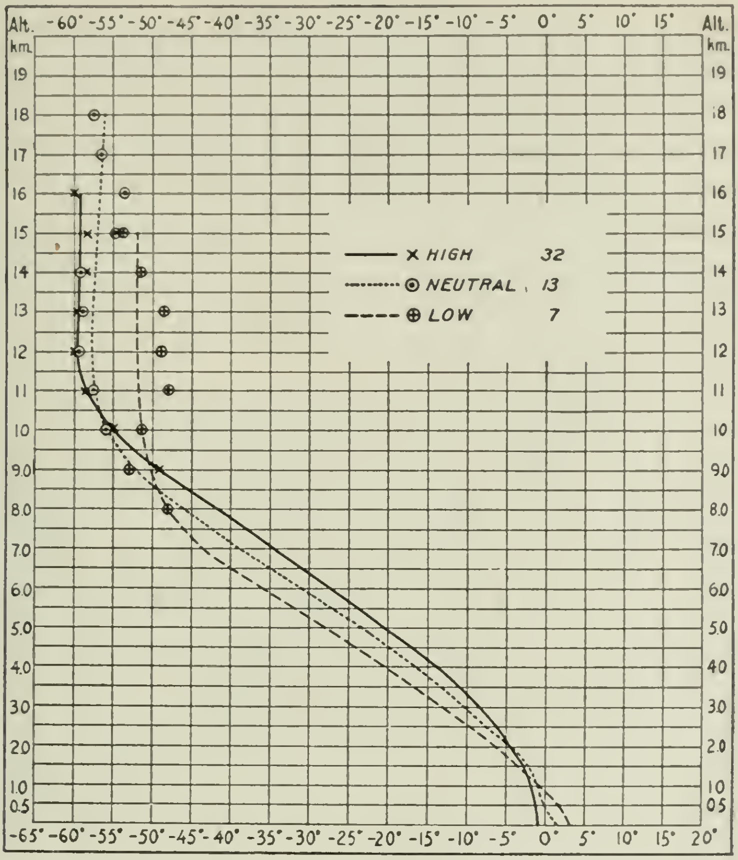
The average of a season's (winter or summer) vertical temperature gradients gives a fairly regular curve, and, of course, the same would be true of the average of these averages, or what might be called the annual gradient for any given locality. However, each particular flight yields its own temperature-altitude curve, which differs more or less from others of the same place and season, especially in the values of the gradients in the first two or three kilometres elevation, in the absolute temperatures at other levels, and in the location of the upper inversion.

With the view of determining the causes of some of these flight-to-flight irregularities, both the summer and the winter records from which the corresponding seasonal gradients were determined were grouped, according to the heights of the barometer at the times and places of observation, into "highs," "neutrals," and "lows." Thus the "highs" belong to barometric readings of 765 mm. or more; the "neutrals" to readings from 757.5 mm. to 762.5 mm.; the "lows" to readings of 755 mm.

or less, all reduced to sea level. While the observations, especially those classed as lows, are not sufficiently numerous to give averages entirely free from irregularities, nevertheless they produce distinct types of curves that any larger number probably would but slightly modify.

Fig. 16 shows the winter averages, respectively, of 32 highs, 13 neutrals, and 7 lows. Commonly, as the figure shows, a high barometer in the winter is accompanied by low surface temperatures, a slow decrease of temperature up to an elevation of about three kilometres, relatively warm air, in general, between the levels of two and nine kilometres, a high upper inversion, and a cold isothermal region. A winter low, on the contrary, and in comparison with a high of the same season, is accompanied by warm surface temperatures, a more rapid decrease of temperature with increase of elevation through the first three kilometres,

FIG. 16.



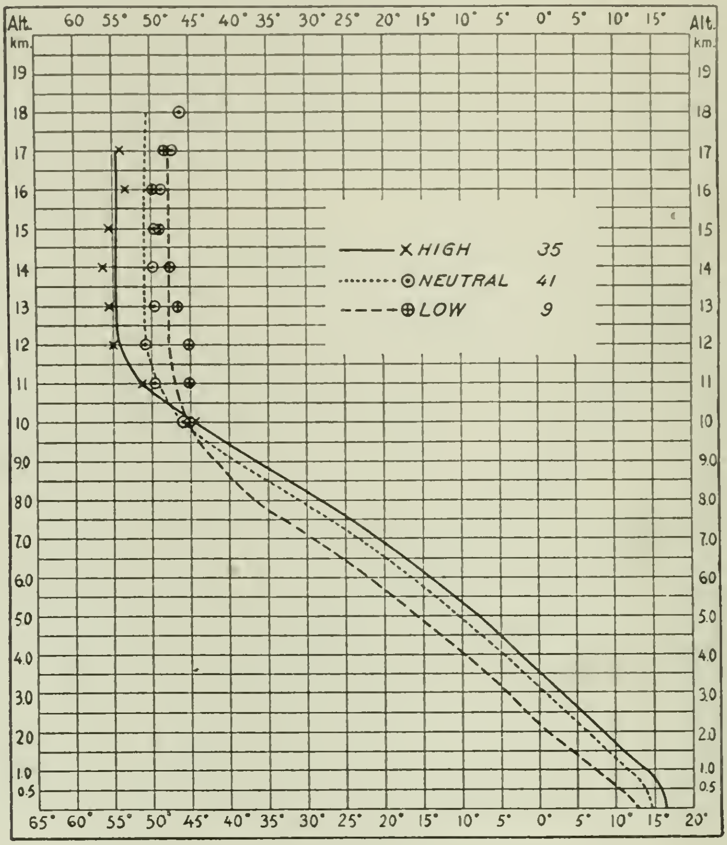
Temperature gradients at different pressures, winter.

relatively cold air from, roughly, two to nine kilometres elevation, a low upper inversion, and a warm isothermal region.

The normal barometer, as one would expect, is accompanied by intermediate values in all particulars.

The corresponding summer gradients (averages, respectively, of 35 highs, 41 neutrals, and 9 lows), given in Fig. 17, show, except near the surface, where the lows remain cold and the highs warm, the same characteristics as do those of winter.

Fig. 17.



Temperature gradients at different pressures, summer.

Both the summer and the winter curves follow exactly the averages of the observations, except for slight deviations in the isothermal region, as shown. Naturally, the higher the level the fewer the observations secured, a fact that explains the irregularities in the isothermal region and justifies, in a sense, smoothing the curves in an effort to distinguish clearly the different types of gradients.

An obvious contributing cause of these differences in temperature is the warming of the air by compression and its cooling by expansion incident to barometric changes; an amount which, starting with dry air at 0° C., is given, as explained on page 163, by the equation

$$\frac{dT}{dp}=\frac{77.6}{p},$$

in which p is the pressure, expressed in millimetres of mercury, and dT the change of temperature in degrees Centigrade.

According to Figs. 16 and 17, the temperature at the altitude of four kilometres is about 7° C. warmer both winter and summer in the regions of high barometric pressure than it is in the regions of low pressure. But to secure this temperature difference as a result of pressure change only, would require a rise or fall of the barometer at this level of about 40 mm., or something like 70 mm. at sea level, and, since this is several-fold the average pressure change, it is obvious that the observed temperature differences cannot in the main be accounted for in this way, though, of course, the pressure effect must be present to some extent.

Another contributing cause of temperature differences, generally associated with the height of the barometer, is the clear and cloudy condition of the sky, or the humid and the dry state of the atmosphere. A barometric high, as we know, commonly is accompanied by clear skies and a dry atmosphere, while in the region of a low the sky ordinarily is overcast, the atmosphere relatively moist, and precipitation abundant—conditions that have much to do with air temperatures. Thus, generally, at the end of any consecutive 24 hours of clear weather the surface of the earth will be warmer in the summer time and colder in the winter because of the unequal lengths during those seasons of the day and night. On the whole, the earth gains heat, especially in clear weather, during summer and loses it in the winter. A cloud covering, however, greatly reduces the rate of this gain or loss, and therefore during winter the surface temperature is lowest when the barometer is high and the earth can radiate most freely to space, while it is warmest when the barometer is low and the sky so overcast as to check radiation loss.

In the summer time, as explained, the conditions of gain and loss of heat are the reverse of those during winter, consequently the highest summer surface temperatures accompany the high barometer, or clear weather, while the lowest accompany cloudy skies.

When the barometer is distinctly above normal the temperature fall with increase of altitude up near the stratosphere generally follows approximately the adiabatic curve for dry air. When, however, the barometer is low the temperature gradient usually is far less constant at all elevations, owing to irregularities in the humidity distribution and the consequent varying amounts and places of precipitation. In many cases the temperature gradient over varying heights is essentially the adiabatic curve for saturated air at the prevailing temperature and pressure; that is, a fall of temperature per given change in altitude is less, other things being equal, the greater the amount of uncondensed humidity present.

Since the curves of Figs. 16 and 17 are the averages of a number of flights, it may be approximately correct, in an effort to account for their differences, to start with something like average conditions and trace the consequences. Let these conditions be a moist atmosphere in the one case and a dry one in the other, each having the same temperature as the other at all levels. The moist atmosphere, because a better radiator than the dry, will, under the same conditions of exposure and at the end of the same interval of time, cool to a lower temperature, but in so doing—that is, in getting rid of its own heat most rapidly—it at the same time supplies heat at greater rate to any neighboring region that receives it by radiation only. Therefore when the lower atmosphere is moist it will, under like conditions, radiate heat most rapidly to and through the always dry air of the isothermal region, and while getting cold itself will at the same time warm this region to a temperature above its average. On the contrary, in the region of a high barometer the lower air, being relatively dry and therefore a poor radiator, will conserve its own temperature, but in so doing will allow the isothermal region to get cold in comparison with its temperature during the prevalence of a low at the same season.

Since the temperature of the isothermal region depends essentially upon the amount of radiation received from the lower atmosphere, it follows that, on the average, the temperatures of the two regions must vary in the same sense, or warm and cool together, and this, indeed, is just what happens, as the winter and summer gradients of Fig. 15 indicate. It is surprising, therefore, when we find the temperatures of these regions varying in the opposite sense, the one getting warm while the other is getting cold. But it must be remembered that the lower atmosphere is warmed convectionally, in large part, while the upper air is warmed almost wholly by radiation. Further, convection must obtain wherever the actual temperature differs from that which gives the equilibrium between absorption and radiation. Hence whatever increases radiation from the lower air, increase of humidity or temperature, or both, must tend to increase the temperature of the isothermal region, and whatever decreases this radiation, decrease of humidity or temperature, or both, must decrease its temperature below that which it otherwise would have. Now the average seasonal change of the lower atmosphere is primarily one of temperature, while the average storm difference of a given season appears to be largely one of humidity. The high temperature of summer obviously affords a more abundant radiation than the relatively low temperature of winter and should give, as we have seen, a warmer isothermal region. Similarly, the different intensities of radiation from humid and relatively dry air would lead one to expect the stratosphere to be warmer over a cyclonic than over an anticyclonic area.

Another important factor, presumably the controlling one, in the temperature contrasts between cyclonic and anticyclonic regions is the vertical movement of the atmosphere, downward in the former, upward in the latter. Probably, at least, a large portion of the anticyclonic excess of air that gives the increase of pressure and makes good the loss by outflow is fed in at considerable altitudes, though below the isothermal level. If the air movement is as here supposed, there necessarily must be dynamical heating throughout the lower atmosphere, partly because of the initially increased pressure, but mainly through descent. At the same time the atmosphere of the isothermal region would be more or less lifted and cooled by the resulting expansion.

Conversely, if, as there is much reason to believe, the chief removal of atmosphere over cyclonic areas is also from considerable altitudes, but below the isothermal region, the lower atmosphere must be dynamically cooled, partly by virtue of the immediately decreased pressure, but chiefly through ascent. The stratosphere would be lowered and its temperature thereby increased. It seems likely, too, that under these conditions there would be a somewhat continuous slow movement of air from the stratosphere down into the region of the troposphere (convection region), with, of course, counterflows elsewhere and subsequent readjustments of the level of the isothermal region as temperature and other conditions changed.

Radiation intensity, barometric pressure, and vertical circulation, therefore, appear all to coöperate in lowering the temperature of the troposphere and raising that of the stratosphere in cyclonic regions. Conversely, they appear equally to coöperate in raising the temperature of the troposphere and lowering that of the stratosphere in anticyclonic regions.

The above temperature conditions are averages, respectively, for the whole of cyclonic and anticyclonic areas. Subdivisions of these areas show temperature contrasts between their several quadrants, owing, in part at least, to differences in horizontal wind direction and the distribution of condensation and evaporation. This interesting detail, however, scarcely belongs to a discussion of the isothermal region, but rather to an account of the two types of weather concerned, under which heads it will receive further consideration.

RELATION OF THE ISOTHERMAL REGION TO LATITUDE.

It is well known that both the height and temperature of the stratosphere are functions of latitude. In the northern hemisphere, during summer, the under surface of the stratosphere gradually rises from about 10 kilometres above sea level at latitude 60° to approximately 15 kilometres at the equator, while the temperature correspondingly changes, roughly, from –45° C. to –70° C. Similar altitude and temperature changes of the stratosphere with latitude obtain, so far as observed, during all seasons and in both hemispheres, though the exact cause, or causes, of these variations is not known.

Changes in the amount of radiation from below and changes in the diathermacy of the upper air at once occur as possible explanations of the above latitude effects. The warm surface temperatures of equatorial regions necessarily cause, through vertical convection, abundant cloudiness at high altitudes. These clouds, in turn, intercept much of the radiation from below, either reflecting or absorbing it. The portion reflected obviously does not directly warm the cloud, but somewhat raises the temperature of the troposphere, while a portion of that which is absorbed merely produces evaporation rather than a change of temperature. Hence, presumably, the high clouds of equatorial regions, and also the considerable humidity there at great altitudes, owing to the persistent vertical convection, raise the level and thereby decrease the temperature of the effective radiating surface, thus diminishing the intensity of the radiation that reaches the stratosphere, and permitting its temperature to be correspondingly low.

Some of the heat thus absorbed in the lower atmosphere conceivably may manifest itself in an acceleration of interzonal circulation in equatorial regions and an increase of outgoing radiation at higher latitudes.

There is, of course, abundant cloudiness over the higher latitudes as well as in equatorial regions, but there the atmosphere is more generally descending instead of ascending, the clouds low, the humid layer shallow, and consequently the effective radiating surface and the stratosphere comparatively warm.

Conceivably, too, the composition of the stratosphere may differ with latitude. Because of auroral concentration and because of any poleward drift there may be of the upper atmosphere, perhaps there is more ozone, intensely absorptive of earth radiation, over high than over low latitudes. Doubtless, also, there are local differences in the water vapor content of the stratosphere, but at most the absolute humidity of this region must be exceedingly small, as is obvious from its excessively low temperature, and from the fact that marked temperature changes of the upper atmosphere, amounting at times to 20° C., or more, never, so far as known, produce clouds above the high cirrus; that is, above the upper levels of the troposphere.

As previously stated, the essential cause of the relation of the temperature of the stratosphere to latitude is not known, but it seems probable that this relation may depend, in part at least, upon the distribution of clouds, water vapor, and ozone, and therefore that each deserves further observation and study in this connection.

CHAPTER V.

COMPOSITION OF THE ATMOSPHERE.

IN the previous discussions the actual composition of the atmosphere was of little or no importance. In some that follow, however, barometric hypsometry, for instance, or the determination of altitude from pressure, it is a factor that cannot always be neglected. It will be convenient, therefore, before considering such subjects, to note of what substances the atmosphere consists and in what proportions they occur.

If we disregard such obviously foreign things as dust, fog, and cloud, then whatever remains appears to be ideally homogeneous, under ordinary conditions, and in many discussions, such as most of those of the previous pages, it conveniently may be so treated. The Greek philosophers, indeed, regarded the atmosphere as one of the four elements that singly and combined constituted the whole of the material universe. To them it was an element in the strictest sense which could not be divided into dissimilar parts.

In reality it is not even a single substance like water, much less a single element, but a mixture of a number of gases and vapors that radically differ from each other in every particular; nor are even the relative percentages of the several distinct constituents at all constant. The story of the chemical conquest of the atmosphere, from the calcination and combustion experiments of the seventeenth and eighteenth centuries that established its complexity down to the refined analyses of the present day that note and account for even the faintest traces, is full of instruction and inspiration. However, it is practicable to give here only some of the final results.

According to Hann,[16] the chief independent gases that are blended into a dry atmosphere at the surface of the earth, and their respective volume percentages, are as follows:

Element......	Nitrogen	Oxygen	Argon	Carbon dioxide	Hydrogen	Neon	Helium
Volume, per cent..	78.03	20.99	0.94	0.03	0.01	0.0012	0.0004

In addition to these, krypton and xenon also occur as permanent constituents of the atmosphere. There are also many substances, such as radio-active emanations, the oxides of nitrogen, ozone, and, above all, water vapor, that are found in varying amounts, but of these only water vapor commonly forms an appreciable percentage of the total atmosphere, a percentage that depends chiefly upon temperature in the sense that, for any given pressure, the higher the temperature the greater the possible percentage of water vapor. This relation holds up to the boiling-point of water at the given pressure, when, assuming saturation, there will be nothing but water vapor present, or its percentage will become 100.

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[16] "Lehrbuch der Meteorologie," 3d ed., p. 5.

Because of this relation of water vapor to temperature its volume percentage decreases from the equator towards the poles, while that of each of the other constituents of the atmosphere correspondingly increases. The annual average values, again quoting from Hann,[17] are:

	Nitrogen	Oxygen	Argon	Water vapor	Carbon dioxide
Equator	75.99	20.44	0.92	2.63	0.02
50° N.	77.32	20.80	0.94	0.92	0.02
70° N.	77.87	20.94	0.94	0.22	0.03

Except for the change in the amount of water vapor, the composition of the surface atmosphere is substantially the same at all parts of the earth. Its composition at different elevations, however, probably differs greatly, as considerations presently to follow will indicate.

But this discussion requires the use of barometric hypsometry. Therefore an equation must be developed for this purpose.

BAROMETRIC HYPSOMETRY.

Let ρ be the density of the atmosphere at the height h, and p its pressure in dynes per square centimetre. Then at the level h the decrease in pressure, $-dp$, due to the increase in height, dh, is given by the equation,

$$-dp=\rho g\,dh \quad\ldots\ldots\quad (1)$$

in which g is the acceleration of gravity at the point in question.

To within limits practically negligible the density of the atmosphere is directly proportional to the pressure—*Boyle's law;* inversely proportional to the absolute temperature—*Charles's law;* and directly proportional to the sum obtained by adding together the molecular weights of the several gases present, each multiplied by the ratio of its partial pressure (the pressure which it alone produces) to the total pressure—*Avogadro's law.*

If, now, ρ_0 is the density of dry air at the temperature 0° C., and under the pressure p, then

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[17] *Ibid.*, p. 5.

$$\rho = \rho_0 \frac{\left(1 - 0.378\frac{w}{p}\right)}{1 + at} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

in which w is the partial pressure of the water vapor present, t the existing temperature in degrees Centigrade, and a the coefficient of gas expansion, or $\frac{1}{273}$, at 0° C.

Substituting the value of ρ, as given by equation (2), in equation (1), we have

$$-dp = \rho_0 g \frac{\left(1 - 0.378\frac{w}{p}\right)}{1 + at} dh \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Further, let H be the height of the "homogeneous" atmosphere, or height it would have if everywhere at the same temperature and pressure, and therefore of constant density. Obviously, according to Boyle's law, the value of H is independent of the actual value of the pressure. If, for instance, the amount of gas is doubled, p becomes doubled and the density doubled, and consequently H remains unchanged. Similarly for any other multiple or submultiple of the pressure.

At any given place the pressure, p, clearly is equal to the continuous product of the gas density, local acceleration of gravity, and homogeneous height; that is,

$$p = \rho_0 g H \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Hence, substituting in (3)

$$-dp = \frac{p}{H} \frac{\left(1 - 0.378\frac{w}{p}\right)}{1 + at} dh \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

But, as is seen from equation (4), H is inversely proportional to g. Hence before we can assign a numerical value to H it is necessary to specify the value of g to which it applies. Now the height of the "homogeneous" atmosphere corresponding to temperature t and gravity g is found by multiplying any barometric height b, representing, under gravity g, a pressure p, by the ratio of the density of mercury at the temperature for which b was determined to the density of dry air at the given temperature t, and assumed pressure p. For 0° C. and normal gravity G (that is, the value of gravity acceleration at sea level at latitude 45° N.),

$$H_G = 7991 \text{ metres.}$$

Therefore H, or, specifically,

$$H_{\cdot} = 7991\frac{G}{g} \text{ metres.}$$

Hence, substituting in (5), and measuring in metres,

$$-7991\frac{dp}{p} = \frac{\left(1-0.378\frac{w}{p}\right)}{1+at}\,\frac{g}{G}dh \ldots\ldots\ldots\ldots \quad (6)$$

Integrating this from h_0, p_0 to h, p, we have

$$7991 \log_e\left(\frac{p_0}{p}\right) = \int_{h=o}^{h=h} \frac{\left(1-0.378\frac{w}{p}\right)}{1+at}\,\frac{g}{G}dh \ldots\ldots\ldots\ldots (7)$$

However, the integration is not rigidly possible, since t and the ratio $\frac{w}{p}$ both are more or less irregular and variable functions of h. The value of g is also a function, but, for any given place, a fixed one, of h. Nevertheless, when the coincident values of p, t, and w are closely known, as they may be, it is quite possible closely to determine the corresponding values of h; that is, to obtain an approximate solution of the above nonintegrable equation. This, of course, is most accurately done by dividing the total height into intervals over each of which t and the ratio $\frac{w}{p}$ both change very nearly uniformly.

If at the elevation h_0 we have the ratio $\frac{w_0}{p_1}$ and at h the ratio $\frac{w}{p}$, then, when $h - h_0$ is not too great, we may, with but little error, assume the ratio constant and its value for the interval in question to be

$$\left(\frac{w_0}{p_0}+\frac{w}{p}\right)/2 = W \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Also, if the temperature varies approximately uniformly between the given levels, we can assume, again with but little error, the mean, t_m, of the two limiting temperatures to be that of the whole layer between h and h_0. Finally, as the value of g changes but little through all attainable levels in the atmosphere, its mean value, g_m, between the two levels, may be used as a very close approximation.

Hence, with all these approximations,

$$H = 7991 \log_e\left(\frac{p_0}{p}\right)\frac{1+at_m}{1-0.378W}\,\frac{G}{g_m} \ldots\ldots\ldots\ldots (9)$$

If, instead of natural logarithms with base e, ordinary logarithms with base 10 are used, the equation becomes

$$H = 18400 \log_{10}\left(\frac{p_0}{p}\right) \frac{1 + at_m}{1 - 0.378W} \frac{G}{g_m} \qquad \text{(10)}$$

Now g_m differs in general from G both because of difference in latitude and because of difference in elevation. Thus the shape of the earth causes the value of gravity so to vary at sea level that at latitude l

$$g_l = G(1 - 0.0026 \cos 2l);$$

while with elevation it varies inversely as the square of the distance from the centre of the earth.

Let R be the radius of the earth at the place of observation, and d the elevation at which the value of g is desired. Then

$$\frac{g_0}{g_h} = \frac{(R+d)^2}{R^2}$$

and

$$g_h = g_0\left(1 - 2\frac{d}{R} + 3\left(\frac{d}{R}\right)^2 - 4\left(\frac{d}{R}\right)^3 + \dots\right) \qquad \text{(11)}$$

But even if d is as great as 10 kilometres, the fraction $\frac{d}{R}$ is still so small, roughly $\frac{1}{637}$, that an error of less than 1 in 400,000 will be made by writing

$$g_h = g_0\left(1 - 2\frac{d}{R}\right)$$

Hence, finally,

$$g_{l,d} = G\,(1 - 0.0026 \cos 2l)\left(1 - 2\frac{d}{R}\right)$$

and

$$h = 18400 \log_{10}\left(\frac{p_0}{p}\right) \frac{1 + at_m}{1 - 0.378W} \frac{1}{(1 - 0.0026 \cos 2l)} \left(\frac{1}{1 - 2\frac{d}{R}}\right) \qquad \text{(12)}$$

But as the amount of water vapor in the atmosphere seldom amounts to more than 2.5 per cent. of the total gases present, it follows that

$\frac{1}{1 - 0.378W} = 1 + 0.378\,W$, to within 1 part in 10,000. Similarly,

$\frac{1}{1 - 0.0026 \cos 2l} = 1 + 0.0026 \cos 2l$, usually to within 1 part in 1,000,000, and

$\left(\frac{1}{1 - 2\frac{d}{R}}\right) = 1 + 2\frac{d}{R}$, when $d = 10$ kilometres, to within 1 part in 100,000.

Hence, for convenience, if $d = \frac{h_0+h}{2}$, we may write as a close approximation,

$$h = 18400 \log_{10}\left(\frac{p_0}{p}\right)(1+at_m)(1+0.378W)(1+0.0026 \cos 2l)\left(1+\frac{h_0+h}{R}\right) \ldots (13)$$

Since the two pressures, p_0 and p, occur in this equation as a ratio, it is correct and customary to substitute for them the corresponding barometric readings—properly corrected, of course—for t and g. But as the value of g, in turn, depends upon h, the evaluation of the latter would appear to require a series of approximations. Rigidly this is true, but, as the value of g varies so little through attainable altitudes, a very rough approximation to the value of h is sufficient for the altitude correction of g.

Obviously, in general, the recorded values of t, W, and the barometric reading b are all in error, and therefore it will be well to see what effects such errors will have on the computed value of h.

Assuming an error to be made in b only, amounting to db, we have from (13), substituting $\frac{b_0}{b}$ for $\frac{p_0}{p}$ and using natural logarithms, $dh = -7991 \frac{db}{b} (1+at_m)(1+0.378W)(1+0.0026 \cos 2l)\left(1+\frac{h_0+h}{R}\right)$ or, very approximately,

$$dh = -7991 \frac{db}{b}(1+at_m)$$

Hence the greater the altitude, or the smaller the value of b, the more important become the errors in pressure. Under the reasonable conditions that $t_m = 0°$ C., $db = 1$ mm., and $b = 500$ mm., corresponding to an altitude of, roughly, 3350 metres, the error $dh = 32$ metres, nearly. Hence, to avoid serious errors in barometrically ascertained altitudes, the value of b must be determined with great care.

Assume, now, an error in the temperature amounting to dt, then $dh = 18400 \log_{10}\left(\frac{b_0}{b}\right) a\, dt$, approximately.

Hence

$$\frac{dh}{h} = \frac{adt}{1+at_m} = \frac{dt}{t_m+273} = \frac{dt}{T}$$

in which T is the absolute temperature.

Again, let $b = 500$ mm., $t_m = 0°$ C., and $dt = 1°$ C. Then

$$dh = 12.25 \text{ metres, approximately.}$$

Clearly, then, to avoid considerable errors in hypsometric altitude determinations the temperature must also be known with considerable accuracy.

Finally, assume an error in the value of W, that is to say, in $\left(\frac{w_0}{p_0}+\frac{w}{p}\right)_2$. As there should be no error of consequence in w_0, assuming it to be the vapor tension at the surface of the earth, it follows that the chief error is likely to be in w, the vapor tension at the elevation where the total pressure is p.

Let w and p both be expressed in terms of barometric height, then

$$dh = 18400 \log_{10}\left(\frac{b_0}{b}\right)(1+at_m)\ 0.378\frac{dw}{2b}$$

If, as above, we let b = 500 mm., then w can scarcely be more than 10 mm. Hence, assuming b_0 = 760 mm., t_m = 0° C., and a 10 per cent. or 1 mm. error in w,

dh = 1.35 metres, approximately.

Hence an error in the value of the humidity produces only a small effect on the altitude determination in comparison with that due to an error of the same order in either the temperature or the total pressure.

Errors in the force of gravity, whether from latitude or from elevation, have already been shown to be very small.

For all ordinary purposes, therefore, altitudes in metres may be determined by the greatly simplified equation,

$$h = 18400 \log_{10}\left(\frac{b_0}{b}\right)(1+at_m) \ldots\ldots\ldots\ldots (14)$$

Obviously these hypsometric formulæ apply only to so much of the atmosphere as is of substantially constant composition, since the same "homogeneous" altitude, 7991 metres, is assumed throughout. Clearly, too, this condition of constant composition must apply, very approximately, up to the greatest altitude to which vigorous vertical convection extends, or in middle latitudes, as we shall see later, to an elevation of about 11 kilometres above sea level.

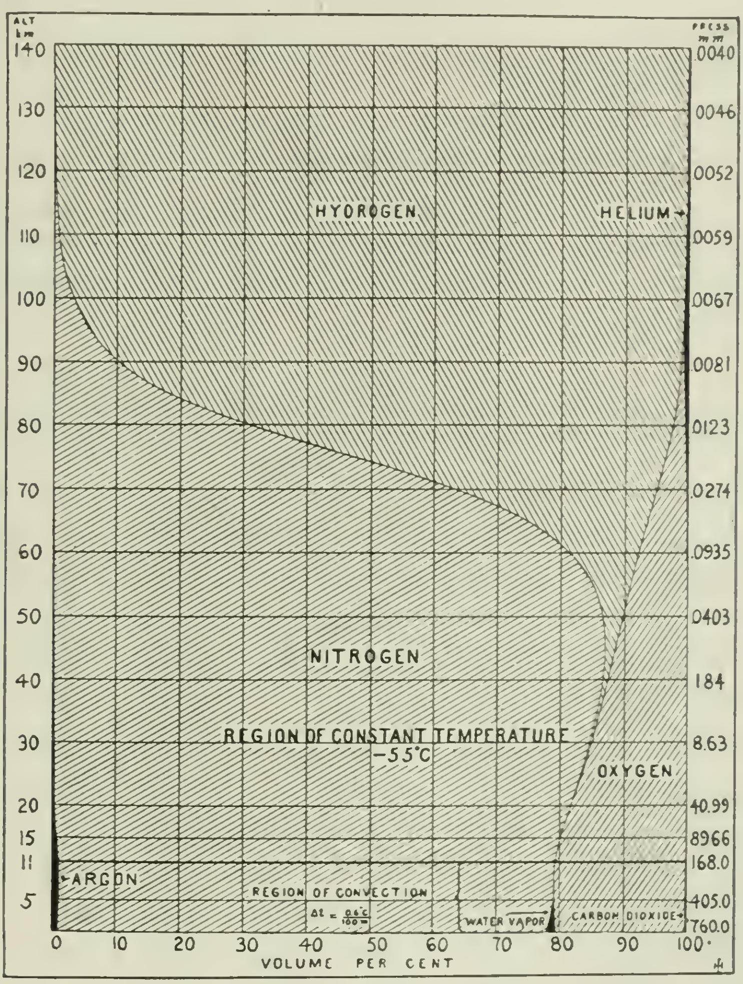
Beyond this level, up at least to the greatest altitude yet reached by sounding balloons and presumably much higher still, the temperature changes comparatively little with change of elevation. Hence in this region there can be relatively little vertical movement of the atmosphere, and therefore a chance, presumably, for the several gases, oxygen, nitrogen, and others, to distribute themselves, each as though it alone were present.

For this more or less isothermal region, then, it is sufficient for most purposes to use the simple equation,

$$-dp = p\frac{dh}{H} \qquad (15)$$

in which p is the partial pressure of the gas under consideration at the place in question, dh the change in elevation, and H the virtual height of the given gas, or its height, assuming its density throughout to be the same as at the initial level, necessary to produce the pressure p. This equation neglects any changes in the force of gravity, but, as already explained, such changes are small, and therefore the equation as it stands gives a close first approxi-

FIG. 18.



Composition of the atmosphere at different levels.

mation. It is not convenient, however, for numerical calculations, but for this purpose can be put into the following form:

$$\log_{10} p = \log_{10} p_0 - \frac{0.434295}{H}(h - h_0) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

Equation (14) is applicable as far up as the composition of the atmosphere is essentially constant, or to an elevation of about 11 kilometres, while above that level, where, owing to the practical absence of vertical convections, each gas presumably is distributed substantially as though it alone were present, equation (16) may be used, with, of course, the proper value of H for each gas considered.

This value is given by the following equation:

$$H = 7991 \frac{D_a}{D} \frac{T}{273}$$

in which T is the absolute temperature, D_a the density of dry air, and D that of the gas in question, both at the same pressure (no matter what) and at 0° C.

Table I, computed by the aid of equations (14) and (16), and Fig. 18, drawn in accordance with this table, give the approximate composition and barometric pressure of the atmosphere at various levels. The assumptions upon which they are based are in close agreement with the average conditions of middle latitudes, and are as follows:

TABLE I.

Percentage Distribution of Gases in the Atmosphere.

Height in kilometres	Gases							
	Argon	Nitrogen	Water vapor	Oxygen	Carbon dioxide	Hydrogen	Helium	Total pressure in millimetres
140	....	0.01	....	.....	....	99.15	0.84	0.0040
130	....	0.04	....	.....	....	99.00	0.96	0.0046
120	....	0.19	....	.....	....	98.74	1.07	0.0052
110	....	0.67	0.02	0.02	....	98.10	1.19	0.0059
100	....	2.95	0.05	0.11	....	95.58	1.31	0.0067
90	....	9.78	0.10	0.49	....	88.28	1.35	0.0081
80	....	32.18	0.17	1.85	....	64.70	1.10	0.0123
70	0.03	61.83	0.20	4.72	....	32.61	0.61	0.0274
60	0.03	81.22	0.15	7.69	....	10.68	0.23	0.0935
50	0.12	86.78	0.10	10.17	....	2.76	0.07	0.403
40	0.22	86.42	0.06	12.61	....	0.67	0.02	1.84
30	0.35	84.26	0.03	15.18	0.01	0.16	0.01	8.63
20	0.59	81.24	0.02	18.10	0.01	0.04	....	40.99
15	0.77	79.52	0.01	19.66	0.02	0.02	....	89.66
11	0.94	78.02	0.01	20.99	0.03	0.01	....	168.00
5	0.94	77.89	0.18	20.95	0.03	0.01	....	405.
0	0.93	77.08	1.20	20.75	0.03	0.01	....	760.

1. That at the surface of the earth the principal gases of the atmosphere and their respective volume percentages in dry air are:

Nitrogen	78.03	Neon	0.0012
Oxygen	20.99	Helium	0.0004
Argon	0.94	Carbon dioxide	0.03
Hydrogen	0.01		

2. That at the surface of the earth water vapor supplies 1.2 per cent. of the total number of gas molecules present.

3. That the absolute humidity rapidly decreases, under the influence of lower temperatures, with increase of elevation, to a negligible amount at or below the level of 10 kilometres.

4. That the temperature decreases uniformly at the rate of 6° C. per kilometre from 11° C. at sea level to −55° C. at an elevation of 11 kilometres.

5. That beyond 11 kilometres above sea level the temperature remains constant at −55° C.

6. That up to the level of 11 kilometres the relative percentages of the several gases, excepting water vapor, remain constant—a result, of course, of vertical convection.

7. That above 11 kilometres, where the temperature changes but little with elevation, and where vertical convection, therefore, is practically absent, the several gases are distributed according to their respective molecular weights.

A number of atmospheric gases—neon, krypton, xenon, ozone, etc.—are omitted both from Table I and from its accompanying figure. This is because all these occur—in the lower atmosphere, at any rate—in quantities too small for graphical illustration in the same diagram and to the same scale as are the principal gases.

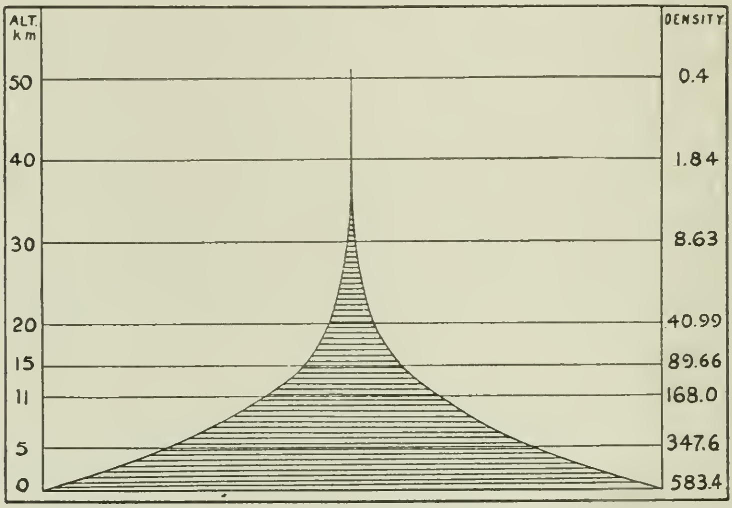
In using this diagram it should be distinctly remembered that it is supported by direct experimental observations only from the surface of the earth up to a level of about 30 kilometres, and that, while the extrapolated values are based upon apparently sound logic and not mere surmises, they necessarily become less and less certain with increase of elevation.

The table and the figure bring out a few points not generally realized. One of these is the fact that the total amount of argon in the atmosphere is much greater than the average total amount of water vapor. Another is the surprisingly small amount of water vapor, especially in view of the wonderful things it does, and of its vital importance to life of every kind. There may also be a little surprise that, according to calculation, the percentage of water vapor reaches a certain maximum at an elevation of 70 to 80 kilometres, where it is, roughly, twenty-fold what it is at, say, 11 kilometres. This, however, does not mean that the total amount of water vapor increases with elevation, but that it decreases less rapidly than do the heavier constituents, and more rapidly than the two lighter ones, hydrogen and helium.

DENSITY OF THE ATMOSPHERE.

Fig. 18, though serving the useful purpose of graphically representing the percentage distribution of the several gases of the atmosphere, nevertheless, is likely to be misleading in respect to their combined density, especially at great elevations. This latter information is shown by Fig. 19, in which the width at every altitude is proportional, approximately, to the corresponding atmospheric density, or at least to as great an elevation, about 40 kilometres, as the size of the figure will permit. Indeed, the density decreases so rapidly with increase of elevation that if at the level of 140 kilometres it is represented by a line only one-fourth of a millimetre long, then at sea level, taking into account difference in temperature and in composition, it would require for its full representation to the same scale a line whose length is, roughly, 600 metres. Obviously, therefore, the density of the atmosphere throughout its known range of, say, 250 kilometres cannot be graphically represented on any convenient scale.

FIG. 19.



Density of the atmosphere at different levels.

CHAPTER VI.

INSOLATION.

THE temperature variations of the atmosphere, both as to time and to place, and also the actual average temperature for any given locality, all obviously are of the utmost importance within themselves, and of equal importance indirectly through such meteorological elements as humidity, precipitation, wind direction, wind velocity, and nearly everything else that contributes to the sum-total of both weather and climate. Hence it is imperative that in any general discussion of meteorology some consideration be given to the question of the source, or sources, of the heat energy necessary to these conditions, where it is delivered, and how distributed.

A little heat is given to the surface of the earth and the atmosphere surrounding it by conduction from the heated interior, a little as a result of certain chemical changes, some from tidal action, and another small amount by the absorption of stellar and lunar radiation. But the sum-total of all these several amounts is so small in comparison to that which results from the absorption of solar radiation that for even a close approximation to the total amount of thermal energy given to the atmosphere it is sufficient to consider the sun as its only source.

The rate at which heat is delivered to the earth from the sun depends upon:

a. The solar output of radiation.
b. Distance from the sun.
c. Inclination of the rays to the plane of the horizon, or solar elevation.
d. Transmission and absorption.

These factors, then, determine the earth's heat income, and will be considered *seriatim*. How this heat is conserved, distributed, and expended also are important problems, which will be taken up later.

SOLAR OUTPUT OF RADIATION.

There is no *a priori* reason for assuming that the total output of radiation from the sun must remain strictly constant from age to age, from year to year, or even day to day. Neither is there any known *a priori* reason for supposing the solar radiation must greatly vary, either periodically or irregularly. Hence it is distinctly a subject for continuous and careful observation, and this sort of observation is already well begun. Beginning with the summer of 1905, Messrs. Abbot and Fowle, of the Astrophysical Observatory of the Smithsonian Institution, and others working with them, have made numerous determinations of the solar constant, or intensity of the solar radiation as received at the outer surface of the atmosphere. Many of these observations were made on consecutive days, especially those obtained on Mount Wilson, California, and show irregular changes both as to time and quantity, changes often amounting to several per cent. in from five to ten days. In general, the observed values of the solar constant varied from one extreme to the other gradually and not by jumps. Besides, observations taken simultaneously, or at least on the same day, at stations so widely separated as Mount Wilson, California, and Bassour, Algeria, gave values that varied substantially together. "Hence," they say, "the most probable conclusion is that the sun actually varies from day to day in its output of radiation within limits of from five to ten per cent. in quantity and in irregular periods of from five to ten days."

The solar variations of even these short periods seem to produce noticeable weather effects,[18] while a change of, say, five per cent. in the solar constant, if long continued, obviously would be a matter of very great climatic importance. A five per cent. increase in the amount of radiation received means, of course, a correspondingly higher temperature equilibrium and, when that is established, a like increase in the amount of radiation that must somehow be sent out to space. An increase in temperature would, among other things, increase the cloudiness to some extent and therefore the amount of solar radiation directly reflected, but probably the chief increase of the outgoing radiation would be due to the greater temperature of the earth and the atmosphere. Suppose the terrestrial radiation to be increased by four per cent., roughly the amount that might be expected from a long-continued five per cent. increase of solar radiation. Then, since the effective absolute temperature of the earth as a full radiator is approximately 260° C.,[19] it follows, from the fourth power law, that the effective temperature increase, essential to this four per cent. greater terrestrial output of radiation, would be 2.6° C., an amount that, if continued for a number of years, would be very important. But, as already stated, the observed periods of solar variations, while irregular, appear always to be short, in fact so short as to produce only much smaller variations from the average temperature.

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[18] Clayton, Smithsonian Miscellaneous Collections, **68**, No. 3, 1917.

[19] Abbot and Fowle, *Annals Astrophys. Obs. Smithsonian Institution,* **2**, p. 175 (1908).

There is, however, some evidence that in addition to these short period changes there are also other changes of the solar constant coincident in period and time with the sunspot variation, and which therefore go through a complete cycle in about 11 years. The evidence in favor of this 11-year cyclic change is not conclusive, but it is found both in the relative pyrheliometric values and in the absolute determinations of the solar constant. Both indicate that the solar constant may be, roughly, two per cent. greater at the times of sunspot maxima than at the times of sunspot minima. This indicated change probably is in the same sense that most persons would anticipate from the fact that the solar surface is most agitated at the times of spot maxima. Nevertheless, it apparently is in direct conflict with the conclusion, supported by much statistical evidence, that the atmosphere as a whole is slightly warmer at the times of spot minima than at spot maxima. There is, however, a logical way out of the paradox which will be given later.

DISTANCE FROM THE SUN.

If the apparent disk of the sun radiated equally all over, it would be strictly accurate to say that the intensity of its energy received at any particular point is directly proportional to the solid angle subtended by it at that point. But it does not radiate equally from all parts, either in amount or kind. The quantity of radiation per unit area of the apparent solar disk decreases from centre to circumference, while at the same time the spectral region of maximum intensity gradually shifts to longer and longer wave-lengths. Hence the total insolation at a given point cannot be rigidly proportional to the solid angle subtended. However, this departure from exact proportionality must in most cases be wholly negligible. Besides, the size of the solid angle subtended by the sun at the surface of the earth is so small that but little error would be made in problems of total radiation by regarding this angle as strictly zero and therefore applying without correction the law of inverse squares.

At aphelion the distance of the earth from the sun is, roughly, 3.3 per cent. greater than at perihelion. Hence the solar constant at perihelion, other things being equal, must be approximately 6.6 per cent. greater than at aphelion. And, since the earth may be regarded as a full radiator at about 260° C. absolute, it follows that its effective temperature must be greater when a maximum than when a minimum by about 1.6 per cent. of the average value, or, roughly, by 4° C.

All these calculations assume complete equilibrium between radiation and absorption, and, while there necessarily is some lag, an approach to equilibrium, as a little calculation will show, probably comes much sooner than one might suppose to be the case. Hence northern winters are not only shorter but also warmer than they would be if they occurred at times of aphelion instead of, as they do, at times of perihelion; while the winters of the southern hemisphere, during which the earth is farthest removed from the sun, have now a maximum both of duration and severity.

Notwithstanding—really, because of—the marked difference between the perihelion and aphelion intensities of the solar radiation at the limit of the atmosphere, it is easy to show that the total amount of insolation on the earth as a whole is constant per constant angular distance along its orbit; and that each hemisphere, regardless of the perihelion phase, or exact date on which perihelion occurs, receives during the course of a whole year exactly the same amount of solar radiation as does the other. This is shown as follows:

Let R be the solar distance, $d\theta$ the angle at the sun swept over by the earth in the time dt. Then, from the law of equal areas,

$$R^2 d\theta = C dt,$$

in which C is a constant.

Also, if dQ is the amount of solar energy incident upon the earth in the time dt,

$$dQ = \frac{I}{R^2} dt$$

in which I is the solar constant at unit solar distance. Hence

$$dQ = \frac{I}{C} d\theta,$$

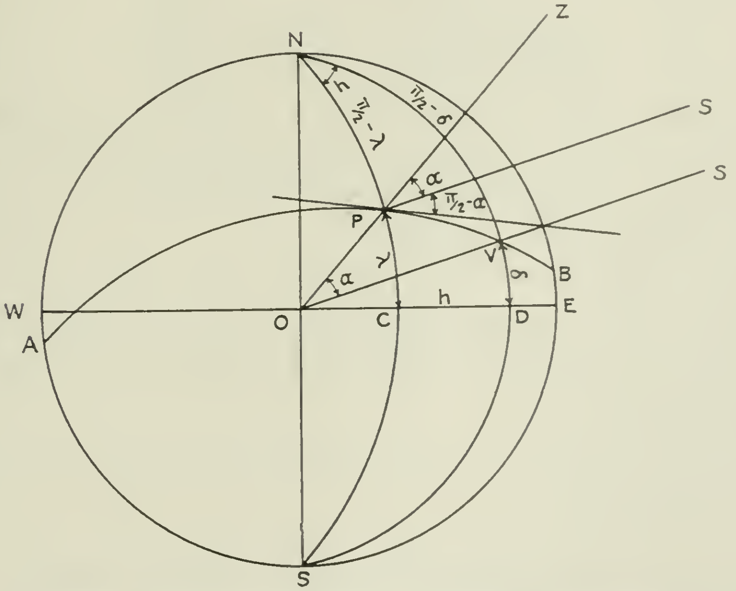
or the energy received by the earth from the sun, assuming the solar output to be constant, is directly proportional to the angular distance between the initial and final radii vectores. Since the direction of the earth's axis is practically fixed in space, it follows that, to the same degree of approximation, each hemisphere must be inclined toward or from the sun over exactly one-half the angular orbit, and hence that the total yearly amount of heat received by one hemisphere is the same as that received by the other, and also that the earth as a whole gets precisely the same amount of radiant energy during the aphelion half of its orbit that it does during the perihelion half—what it loses in distance it exactly makes up in time.

It must not be supposed that this equality of heat supply means equality of world temperatures. Indeed, it means quite the reverse, for the equal quantities are delivered in unequal times; the time being longest and therefore the world temperature the lowest, except in so far as there may be a lag, during aphelion, and shortest with highest temperature, as previously explained, during perihelion.

SOLAR ALTITUDE.

Leaving out, for the present, all questions of atmospheric absorption, it is obvious that the intensity of insolation is directly proportional to the sine of the angle of solar altitude, or to the

FIG. 20.

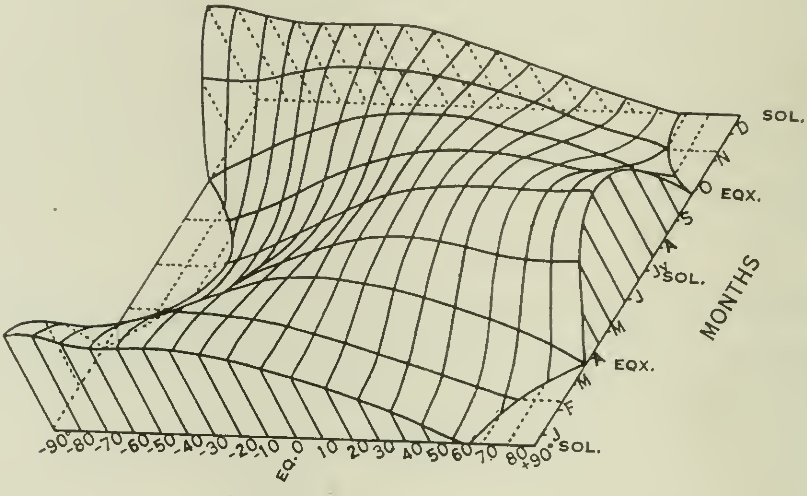


Relation of insolation to latitude, declination, and hour angle.

cosine of the sun's zenith distance. But neither of these angles is directly known, and therefore can be expressed only in terms of those that are known. Each, however, is a function of latitude, of the time of day, expressible as an hour angle, and solar declination, as will be explained by the aid of Fig. 20.

Let P be the point of observation, with its zenith at Z, and let the sun be off in the direction OS or PS. Clearly, then, the plane of OZ and OS intersects the surface of the earth in a great circle, and the angle ZOS, measured by the arc PV of this circle, is equal to the sun's zenith distance. But in the spherical triangle NPV it is obvious that the arc NV, V being directly under the sun, is the codeclination, NP the colatitude, and the angle h at N, measured by the arc CD on the equator, the hour angle, or angle through which the earth must turn to bring the meridian of P directly under the sun. Hence

FIG. 21.



Relation of insolation to season and latitude.

$$I_n = I \cos \alpha = I \ (\sin \phi \sin \delta + \cos \phi \cos \delta \cos h),$$

in which I_n is the normal component of the full solar intensity I, φ the latitude of the point P, δ the solar declination, and h the hour angle, as explained.

To find the amount of solar energy delivered at a given point we have the equation,

$$dQ = I_n dt = I \ (\sin \varphi \sin \delta + \cos \varphi \cos \delta \cos h) \ dh$$

in which dh is the change in the angle h in the time dt. To obtain the total energy delivered per unit area in the course of a day we may consider I and δ constant for that time, and therefore write,

$$Q = 2I\ (\sin \varphi \sin \delta\ H + \cos \varphi \cos \delta \sin H)$$

in which H is the hour angle between noon and sunrise or sunset.

H obviously is a function of φ and δ. Thus at sunrise, say, $a = \frac{2}{\pi}$. Hence,

$$\cos \alpha = 0 = \sin \varphi \sin \delta + \cos \varphi \cos \delta \cos H$$

and

$$\cos H = -\tan \varphi \tan \delta.$$

Now φ, the latitude of the place in question, is known, and δ, the solar declination for any given day, is obtainable from an ephemeris. Hence, assuming a constant output of solar energy and allowing for variations in solar distance, the relative per diem amounts of insolation delivered to the earth (outer atmosphere) at different latitudes and different times may readily be computed. A few of these values, in terms of the total insolation received at the equator on the day of the vernal equinox, are given in the following table, and the complete data for all seasons and all latitudes in Fig. 21, both of which are copied from Davis's "Elementary Meteorology," Ginn & Co.:

Latitude..........	0°	+20°	+40°	+60°	+90°	−90°
March 20.........	1.000	0.934	0.763	0.499	0.000	0.000
June 21...........	0.881	1.040	1.103	1.090	1.202	0.000
September 22......	0.984	0.938	0.760	0.499	0.000	0.000
December 21......	0.942	0.679	0.352	0.000	0.000	1.284
Annual total....	347	329	274	197	143	143

TRANSMISSION AND ABSORPTION.

The rate of solar output of energy, distance from the sun, length of day, and solar altitude are all, as above explained, of vital importance in determining the amount of radiant energy delivered to unit horizontal area during any interval of time—any consecutive 24 hours, say. But they give only the quantity of insolation delivered, and not the amount of energy actually absorbed and thereby rendered effective in maintaining temperature. This smaller quantity, the absorbed energy, depends upon not only the total insolation and therefore upon each of the above factors, but also upon at least two others; namely, reflection and scattering. Thus it is obvious that all that solar radiation which is reflected back to space, whether by clouds or by the surface of the earth, is immediately and completely lost, so far as heating the atmosphere is concerned, and that the same is also true of that smaller portion lost through the process of scattering, whether by dust particles or by air molecules.

The total loss of insolation by these two processes, reflection and scattering, amounts, according to Abbot and Fowle,[20] to about 37 per cent. for the whole earth. In other words, more than one-third of all the energy delivered to the earth is unused—merely scattered to space.

When solar radiation is minutely analyzed spectrally it exhibits thousands of irregularities in the wave-length distribution of energy that were present even before the outer atmosphere was reached. The minima, indicating strong absorption in the solar atmosphere, constitute the well-known Fraunhofer lines.

In addition to the vast number of intensity deficiencies, absorption or Fraunhofer lines, as they are called, inherent in solar radiation, there are also many similar deficiencies resulting from its passage through the earth's atmosphere. These are caused by oxygen, carbon dioxide, water vapor, and ozone, and possibly even by other substances. Three of these, carbon dioxide, water vapor, and ozone, are also strongly absorptive of the long wave-length earth radiation. Oxygen and water vapor have many exceedingly restricted regions of absorption—so restricted, indeed, that in mere appearance they are indistinguishable from the narrow Fraunhofer lines. But in addition to these numerous narrow lines there are also a number of broad absorption bands, certainly of water vapor, ozone, and carbon dioxide. Oxygen, too, seems to have a broad absorption band in the region of exceedingly short wave-lengths. It is possible that many, if not all, of the bands are simply aggregates of large numbers of individual lines, but this is not known to be true of any of them.

Whatever the actual process of absorption, it is certain that to within observational errors the amount of energy absorbed increases arithmetically with the intensity of the incident radiation and geometrically with the quantity of the absorbing material passed through, provided it is all under the same physical condition. Thus if I_0 is the initial intensity of a beam of parallel radiation, and aI_0 its intensity after passing normally through a homogeneous layer of absorbing material of unit thickness, then its intensity after traversing a distance of m units in the same material is given by the equation,

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[20] *Annals Astrophys. Obs. Smithsonian Institution*, 2, p. 163.

$$I_m = I_0 a^m.$$

In the case, also, of scattering of radiation the extinction progresses according to the same laws that apply to absorption. That is to say, it is always a constant fraction of the remaining radiation that gets through a unit quantity of the scattering material.

The coefficients both of direct absorption and of extinction by scattering are radically different for radiations of different wave-lengths. But if I_0 is the initial intensity of the radiation of a given wave-length and aI_0 its intensity after it has passed normally through a layer of absorbing material of unit thickness, then after normal transmission through layers m and n units thick respectively,

$$I_m = I_0 a^m, \text{ and } I_n = I_0 a^n$$

Hence,

$$a = \left(\frac{I_m}{I_n}\right)^{\frac{1}{m-n}}, \text{ and } I_0 = I_m \left(\frac{I_m}{I_n}\right)^{\frac{m}{n-m}}$$

Now, in the case of the atmosphere, while in a vertical direction there is neither homogeneity in dust content nor in density, there is approximate horizontal homogeneity in respect to both conditions. Hence by observing the sun at different angles of elevation a considerable range in the ratio between m and n can be obtained for the atmosphere as a whole.

For simplicity it is desirable to take $n = 2m$, from which,

$$I_0 = \frac{I^2_m}{I_{2m}} \text{ (equation of Bouguer).}$$

As both I_m and I_n are measurable, anywhere at the surface of the earth, I_0, or the intensity of the radiation outside the atmosphere, is at once determined to approximately the same degree of accuracy. The equation, however, is accurate only for monochromatic radiation. If applied to the whole, or even any considerable part, of the solar radiation as a unit the value thus obtained for the intensity of the initial radiation will be too small, as Langley showed long ago. This can be seen as follows:

Let the intensities of the several monochromatic radiations be A_0, B_0, C_0, etc., and their respective coefficients of transmission a, b, c, etc. Then their combined residual intensities after passing through the thickness m and $2m$ of the absorbing medium will be, respectively,

$$A_0a^m+B_0b^m+C_0c^m+, \text{ etc.}=R_m$$

and

$$A_0a^{2m}+B_0b^{2m}+C_0c^{2m}+, \text{ etc.}=R_{2m}$$

Hence the initial intensity, as computed by the Bouguer equation, is

$$R_0=\frac{R^2_m}{R_{2m}}$$

But the difference between the actual and the computed initial intensity is

$$A_0+B_0+C_0+, \text{ etc.}-R_0=$$

$$A_0+B_0+C_0+\text{ etc.}-\frac{(A_0a^m+B_0b^m+C_0c^m+\text{etc.})^2}{A_0a^{2m}+B_0b^{2m}+C_0c^{2m}+\text{etc.}}=$$

$$\frac{A_0B_0(a^m-b^m)^2+A_0C_0(a^m-c^m)^2+\ldots\ldots+B_0C_0(b^m-C^m)^2+\text{etc.}}{A_0a^{2m}+B_0b^{2m}+C_0c^{2m}+\text{ etc.}}$$

An occasional term in the numerator of this final fraction may reduce to zero, since possibly $a = k$, $c = l$, etc., but in general no two of the coefficients, a, b, c, etc., are equal to each other. Hence every term in the numerator, except the few zero ones, if such exist, and consequently the fraction as a whole, is both real and positive. The Bouguer equation, therefore, when applied to complex radiation, always gives too small a value for the initial intensity.

Clearly, then, to determine to the highest degree of accuracy the intensity of the radiation reaching the outer atmosphere (that is, the amount per unit normal surface per unit time) it is necessary first to analyze it into its spectroscopic components and then either to determine the initial intensity of each or else to adopt some equivalent process. The direct method of measuring the energy in each small spectral range would be very tedious, and, besides, would involve a difficult instrumental standardization, hence the following method has been found more convenient:

1. Analyze the insolation and obtain, with the bolometer, the relative distribution of energy through the spectrum for different solar altitudes but, as nearly as possible, constant sky conditions.

In each case the value of m, the air mass as it is called, is proportional to the secant of the solar zenith distance. Hence when the solar altitudes at which the bolograms were taken are known, the ratios of the corresponding m's, being the ratio of the respective zenith distance secants, are also known.

2. Measure with a pyrheliometer the rate at which solar energy, exclusive of sky radiation, is delivered per unit normal area during the same time that one of the bolograms was being obtained.

3. Extrapolate, according to the Bouguer equation, each portion of the bolograms to zero atmosphere and thus obtain the initial bologram, or energy distribution through the solar spectrum outside the atmosphere.

4. Measure the areas between the base line, corresponding to zero insolation, and the two bolograms, the extrapolated and the one corresponding to the pyrheliometric reading.

5. From these areas, A_0 and A, respectively, and the observed solar intensity I, compute I_0, the intensity of solar radiation outside the atmosphere, by the equation,

$$I_0 = I \frac{A_0}{A}$$

When expressed in terms of gram-calories per square centimetre normal surface per minute the average value of I_0, known in this form as the solar constant, is about 1.93.[21]

As stated above, careful estimates show that about 37 per cent. of this radiant energy is wholly lost to the earth, leaving only some 63 per cent. directly absorbed in roughly equal amounts by the earth and the atmosphere. But since the reflecting power of the earth is small, and since the air usually is nearly opaque to terrestrial radiation, it follows that approximately 60 per cent. of the incident solar energy ultimately heats the atmosphere.

The more conspicuous notches in the bolometric curve coincide with water vapor absorption bands, from which it is inferred that most of the direct absorption of solar energy in the atmosphere is due to water vapor. All these bands, however, are of longer wave-length than the region of maximum intensity in the solar spectrum, as are also the absorption bands of carbon dioxide and the stronger bands of ozone. Nitrogen and argon have no known absorption bands, while oxygen, the only other important constituent of the atmosphere, has only one, and that in the extreme ultraviolet or Schumann region. Further, the general absorption of all three is so feeble that, to a first approximation, it may be regarded as wholly negligible. Hence atmospheric absorption of radiation, whether solar or terrestrial, obviously is due almost wholly to water vapor, carbon dioxide, and ozone; and, since the approximate amount of carbon dioxide in the atmosphere is always known and that of water vapor at least often determinable, it frequently is possible, by the aid of laboratory data, to know roughly the actual absorption in any portion of the spectrum due to these two substances, either singly or jointly.

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[21] Abbot and Fowle, *Annals Astrophys. Obs. Smithsonian Institution*, 3, p. 134 (1913).

The magnitude of the ozone effect, however, is always uncertain because the quantity of this gas in the atmosphere is not known. In the presence of moisture and at ordinary temperatures it soon reverts to ordinary oxygen—a sufficient reason, perhaps, why only traces of it are found in the lower atmosphere. In the high atmosphere, on the other hand, where there must be very little moisture and where the temperature in mid-latitudes is about –55° C., and even lower in the tropics, it obviously is far more stable. Hence, since extreme ultraviolet radiation, such as there is every reason to believe is emitted by the sun, on passing through cold dry oxygen converts much of it into ozone, it appears exceedingly probable that this substance must exist to appreciable amounts in the higher portions of the atmosphere. Indeed, this probability may be regarded as reduced very nearly to a certainty by Ångström's [22] discovery of two solar spectrum bands coincident with ozone absorptions at about $\lambda 4.7\mu$ and $\lambda 9.5\mu$, respectively; and by an investigation by Fabry and Buisson [23] which shows that the observed limit of the solar spectrum appears to be fixed by that ozone band of extraordinary absorptive power whose maximum occurs at about $\lambda 0.254\mu$. Presumably, then, there is sufficient ozone in the atmosphere to be of importance with respect to both the incoming and outgoing radiation.

The form of the solar energy spectrum curve outside the atmosphere as determined by Abbot and Fowle and its comparison with "black-body" curves at 6200° and 7000° absolute C. are given by Fig. 22, a copy of Fig. 29, vol. iii, *Annals of the*

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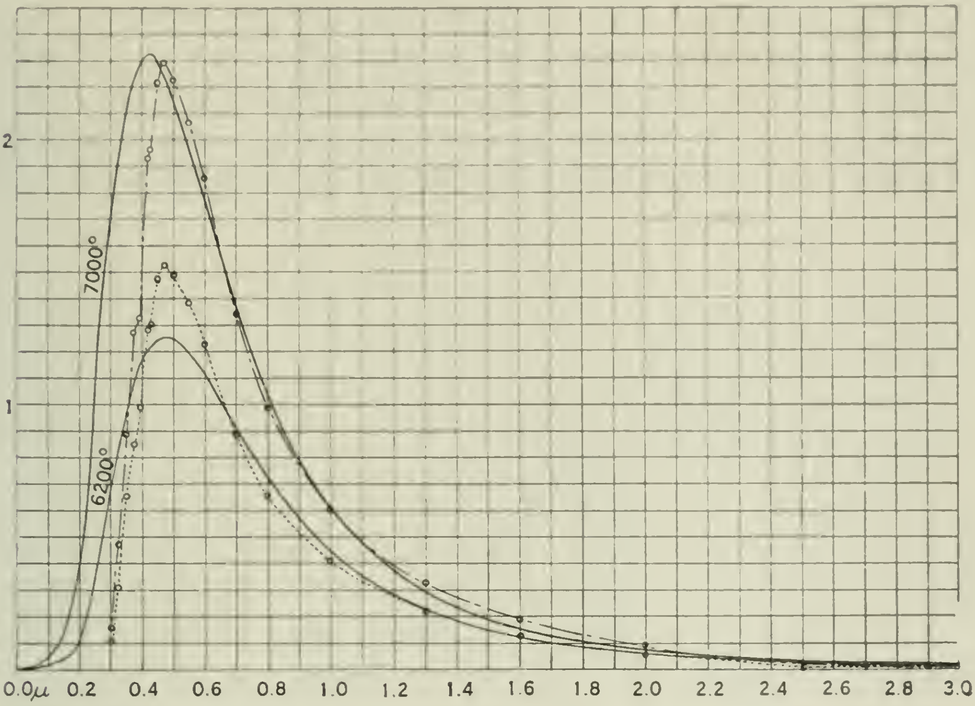
[22] *Arkiv. för Matematik, Astronomi och Fysik.*, 1, p. 395 (1914).

[23] *Journal de physique* (5), 3, p. 196 (1913).

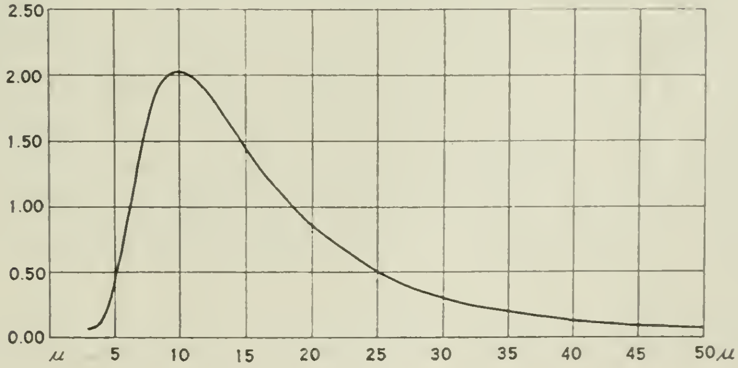
Astrophysical Observatory of the Smithsonian Institution. The curve of terrestrial radiation intensities, on the other hand, is not known, but it obviously must be within that of a full radiator at the earth's temperature, but close to it, because of the universal presence of the highly absorptive substances, water vapor, especially, carbon dioxide, and ozone. That is, it must be within, but close to, the black-body curve for 287.2° C. absolute, as shown

FIG. 22.



Comparison of solar and "black-body" energy distribution.

FIG. 23.

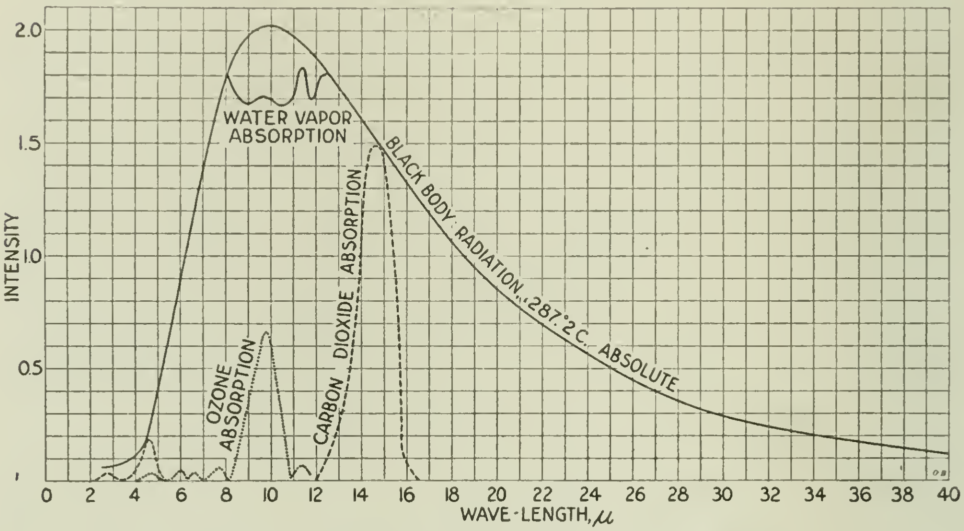


"Black-body" radiation at earth temperature.

in Fig. 23, copied from Plate XX, vol. ii, *Annals of the Astrophysical Observatory of the Smithsonian Institution* (Abbot and Fowle).

The absorptions of earth radiation by water vapor, carbon dioxide, and ozone are shown in Fig. 24. The outer or enveloping curve, a copy of Fig. 23, gives the intensity distribution of radiation from a black body at the temperature 287.2° C. absolute. The area of this curve below the irregular full line near its top, at least up to 20μ, and, presumably, through much, if not all, the region of longer wave-lengths, shows the absorption of earth radiation by a column of 1.13 grammes of water vapor per square centimetre cross-section, as computed by Bouguer's equation from the laboratory data of Rubens and Aschkinass.[24] The amount of water vapor assumed, 1.13 grammes per square centimetre cross-section of the column, is that which Abbot and Fowle[25] have computed to be the average amount in the atmosphere as a whole above the 1780-metre level. The areas below the two broken curves show the absorption by carbon dioxide above the same level, as computed from the experimental data of Schae-

Fig. 24.



Water vapor, carbon dioxide, and ozone absorption.

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[24] *Ann. der Phys.*, 64, p. 584 (1898).

[25] *Annals of the Astrophys. Obs. Smithsonian Institution*, vol. ii, p. 168 (1908).

fer,[26] and Rubens and Aschkinass.[27] Finally, the area below the dotted line gives some idea of the absorption of earth radiation by ozone, computed, after making certain assumptions explained below, from the observations of Ladenburg and Lehmann.[28] The amount of the ozone absorption, however, is uncertain, as implied, for several reasons: (*a*) Laboratory measurements have not extended beyond 12μ. (*b*) While Ladenburg and Lehmann give the length of the absorbing column used, one metre, and describe minutely their ingenious manometer, they do not state the actual pressures at which their data were obtained. But as their ozone was nearly pure, and as they refer to the color of the gas at 50 mm. and 200 to 300 mm., it would seem that they used the equivalent, roughly, of a column 30 centimetres long at, say, 15° C. and 760 mm. (*c*) The amount of ozone in the atmosphere is not known. Pring,[29] who appears to have done the most careful work on this subject, estimates it to be the equivalent of a layer of the pure gas 4.2 centimetres thick at normal temperature and pressure. Hence the assumptions referred to above were (1) that the ozone in the absorption tube was the equivalent of a column 30 centimetres long, and (2) that the ozone in the atmosphere is equivalent to a layer whose thickness is only 4.2 centimetres, each at atmospheric pressure and room temperature.

It appears, then, as shown by Fig. 24, that the absorption of earth radiation by water vapor is nearly perfect, even beyond the level of one to two kilometres; that neither at this level nor, perhaps, at any other (consult Fig. 18 and its accompanying table for probable distribution of carbon dioxide and water vapor) does the carbon dioxide appreciably affect the amount of absorpinto—already complete (through the presence of water vapor) in the regions of its bands; and that, since ozone absorption is very strong where that of water vapor is weakest and imperfect and earth radiation at its maximum, the presence of this gas in the atmosphere has a slight heat-conserving or warming effect.

It is also obvious that, although each of these substances is an effective absorber in the region of appreciable to strong solar radiation, their joint effect on earth radiation is far greater, so much so, indeed, that for low levels it is practically complete.

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[26] *Ann. der Phys.*, 16, p. 93 (1905).

[27] *Loc. cit.*

[28] *Ann. der Phys.*, 21, p. 305 (1906).

[29] *Proc. Roy. Soc., A*, vol. 90, p. 204 (1914).

SURFACE TEMPERATURES AND ABSORBING GASES.

The radiation from a particle of water vapor, or any other substance in or of the atmosphere, clearly is equal in all directions. Hence the amount of radiant energy incident on the surface of the earth and the resulting temperature are generally different from what they would be in the absence of any such absorbing and radiating medium. During the night, when there is no incoming radiation to consider, the process of absorption and radiation by the constituents of the atmosphere manifestly checks the rate of surface cooling, and thereby insures higher night temperatures than otherwise would obtain. Whether this process also increases day temperatures is not so obvious. It does, as the following argument will show, when and only when the substance involved, whether the ozone shell, presumably in the isothermal region, the water vapor shell of the lower atmosphere, or any other such shell, is more absorptive of the outgoing terrestrial radiation than of the incoming solar radiation.

The numerical solution of the problem as applied to any one of these shells is complicated by the alternation between night and day; by constant changes in the solar inclination; by reflection; and probably by many other conditions of importance. However, since the coefficient of absorption is independent of intensity of radiation, it is possible to obtain an approximate evaluation of the temperature effect due to any given absorbing layer or shell.

Let I be the average intensity of the normal component of the absorbed portion of solar radiation: that is, assuming, as already explained, that 37 per cent. of the incident solar energy is wholly lost by reflection, and representing the solar intensity outside the atmosphere by I_0, then, dividing the cross-section of the beam, multiplied by its effectiveness, by the area over which it is distributed,

$$I = \frac{0.63 I_0 \pi R^2}{4\pi R^2} = 0.16\ I_0,\ \text{about},$$

in which R is the effective radius of the earth as an intercepter of incoming radiation.

Also let aI be the average intensity of solar energy, including both the direct and the reflected, absorbed by the outermost shell, say, or by the ozone of the upper atmosphere. Half this absorbed energy is radiated to space and half to the earth, including the lower atmosphere.

The earth, which for convenience may be considered initially cold, now receives radiation of the average intensity $(1-a)\ I$ from the sun, and of the intensity $\frac{a}{2}\ I$ from the absorbing layer under consideration. Together these amount to $I\ (1-\frac{a}{2})$.

After a time the earth will return an equal average radiation, but of very different spectral distribution. Let $b\,I\ (1-\frac{a}{2})$ be the part of this long-wave earth radiation absorbed by the layer in question. As before, one half, or $\frac{b}{2}\ I\ (1-\frac{a}{2})$, will be radiated back to the earth, there absorbed, because of its long wave-length, and again sent out. The next amount returned by the shell is $\left(\frac{b}{2}\right)^2 I\ (1-\frac{a}{2})$, and so on infinitely.

Hence the total average intensity, I_e, of the radiation reaching the earth and lower atmosphere is given by the equation,

$$I_e = I\left\{1-\frac{a}{2}\right\}\left\{1+\frac{b}{2}+\left(\frac{b}{2}\right)^2+\ldots\ldots+\left(\frac{b}{2}\right)^\infty\right\}$$

$$= I\left\{1+K(b-a)\right\}-\frac{a}{2}\left(\frac{b}{2}\right)^\infty$$

$$= I\left\{1+K(b-a)\right\},\ \text{since } b \text{ cannot exceed unity,}$$

in which

$$K = \frac{1}{2}\left\{1+\frac{b}{2}+\left(\frac{b}{2}\right)^2+\ldots\ldots+\left(\frac{b}{2}\right)^\infty\right\}$$

Now, b is positive and therefore K is also positive. Hence

$$I\left\{1+K(b-a)\right\}\substack{>\\=\\<} I$$

according as

$$b \substack{>\\=\\<} a$$

That is, the total amount of radiation reaching the earth is increased, unchanged, or decreased by the presence of an absorbing shell according as its coefficient of absorption of terrestrial radiation is greater than, equal to, or less than its coefficient of absorption of solar radiation. But water vapor, carbon dioxide, and ozone are all more absorptive of earth radiation than of the comparatively short wave-length solar energy, and therefore each, but water vapor especially, keeps the average temperature higher than it otherwise would be.

Suppose $b = 20$ per cent. and $a = 2$ per cent., then,

$$I\left\{1 + K(b-a)\right\} = 1.1 I, \text{ about.}$$

That is, the incoming radiation, and hence also the outgoing radiation, is increased 10 per cent. over what it would be if such an absorbing layer did not exist. But as the earth, largely because of its water vapor, radiates substantially as a black body, or in proportion to the fourth power of the absolute temperature, it follows that a 10 per cent. increase of radiation implies approximately a 2.5 per cent. increase of the absolute temperature. In other words, an absorbing shell with the properties assumed, properties that possibly are of the same order of magnitude as those of the existing ozone in the upper atmosphere, would maintain the average temperature of the earth about 7° C. higher than it otherwise would be.

Any increase, then, in the amount of ozone, or other similar absorbing material, in the outer atmosphere must more or less increase the average temperature of the earth. Hence variations in the output from the sun of the ozonizing or very short wavelength radiation presumably would alter the ozone content of the upper air and through it, as above explained, the average temperature of the earth. Other things being equal, it would seem that there should be a maximum of this extreme ultraviolet radiation and, consequently, maximum average temperature at the time of a sunspot minimum when the solar atmosphere is comparatively clear, as indicated by a minimum corona; and a minimum, with minimum average temperature, at the time of a spot maximum when the "dustiness" of the solar atmosphere, as shown by a maximum corona, is very great. Even if the solar constant should be a little greater at the time of a spot maximum than at a spot minimum, the above variation of ozone, if it occurs, might lead to the paradoxical concurrence of maximum average temperature with minimum average insolation and minimum average temperature with maximum average insolation.

(*To be continued.*)

MODERN DYNAMO ELECTRIC MACHINERY.*

BY

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TURBO-ALTERNATORS.

The history[17] of the development of the turbo-alternator begins about 1889, when a 75-kilowatt machine was built by the Parsons Company to operate at 4800 revolutions per minute. Some of the other early turbo-alternators developed by this company were:[18]

Date	Kilowatts	R.P.M.	Poles	Remarks
1889	75	4800	2	Rotating armature type with surface ventilation.
1891	150	4800	2	Rotating armature with radial ducts fed by axial holes.
1894	350	3000	4	Rotating armature with axial ducts and a fan at one end.

It is of interest to note that, as early as 1894, Parsons had used both radial and axial ventilation; even to-day there is much controversy as to which is the most satisfactory for modern turbo-alternators.

By 1899 the output had become so large and the voltage so high that it was no longer considered desirable to use the rotating armature type of machine, and so the rotating field type gradually won favor. The Brown Boveri Company, from the start in 1901, have built the smooth drum type of rotor, shown in Fig. 57, their purpose being " to subdivide the field winding into a number of slots with a view to distributing the centrifugal force of the winding, the whole of the field iron being thereby brought into close proximity with the armature surface and the space between the usual salient polepieces being utilized.

Up until 1905 two methods were used to cool these machines. In the older method standard slow-speed practice was followed, the air being stirred up around the machine and the exposed surface made as large as possible. In modern practice, however, the machine is totally enclosed so that it will operate quietly while air is forced through the machine and directed on the surfaces to be cooled.

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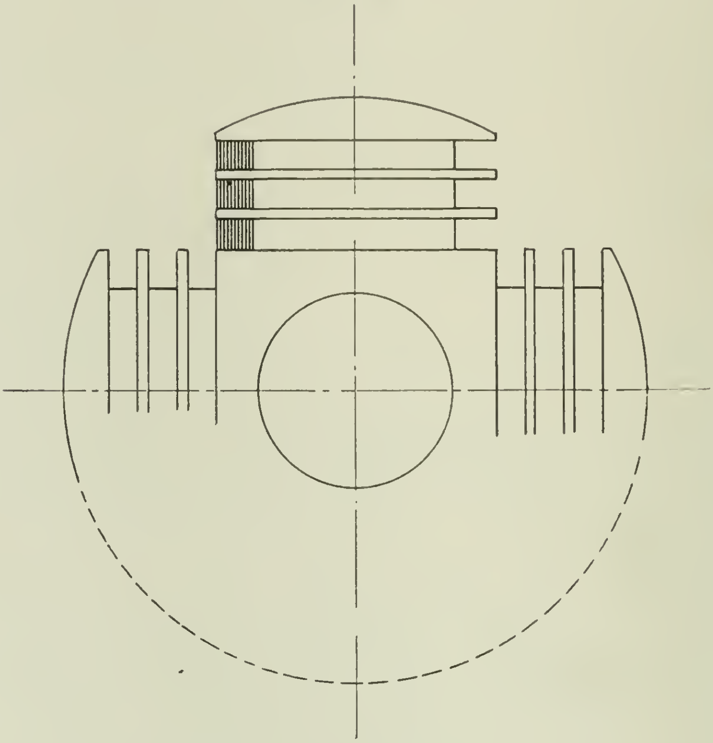
* Continued from page 226, August issue.

[17] "The Engineering Evolution of Electrical Apparatus," Lamme, *Electric Journal,* vol. ii, p. 221, 1914.

[18] "High-speed Electrical Machinery," Storey and Law, *Journal of the Institution of Electrical Engineers*, vol. 41, p. 286, 1908.

In those days, also, there was much discussion as to the best type of turbo-rotor.[19] Some had salient poles as shown in Fig. 56, others were of the cylindrical drum type as shown in Figs. 57 and 58, some were built up out of laminations and others of 2½-inch disks mounted on a shaft, some were solid forgings and others were of cast steel. There was much argument as to the relative merits of the salient pole and of the cylindrical type of construction, and this subject was finally thrashed out in the discussion of a paper[20] by Miles Walker in 1910, by which time it had become apparent to designers of turbo-alternators of large output that the cylindrical type of rotor was

FIG. 56.



High-speed rotor with salient poles.

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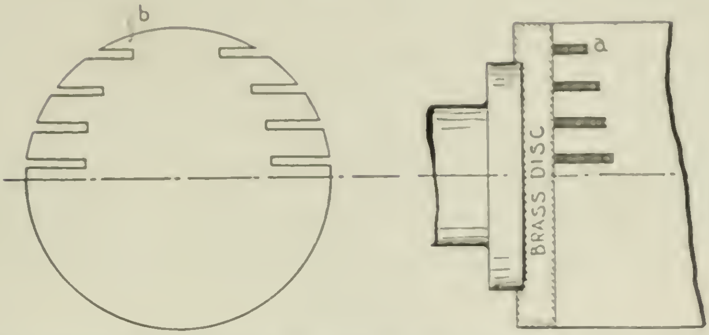
[19] "Steam Turbine Dynamos," Ellis, *Ibid.*, vol. 37, p. 305, 1906.

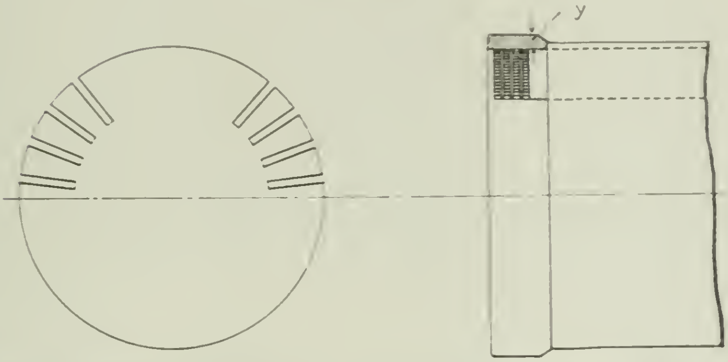
[20] "Design of Turbo Field Magnets for Alternate-current Generators," Walker, *Ibid.*, vol. 45, p. 319, 1910.

FIG. 57.



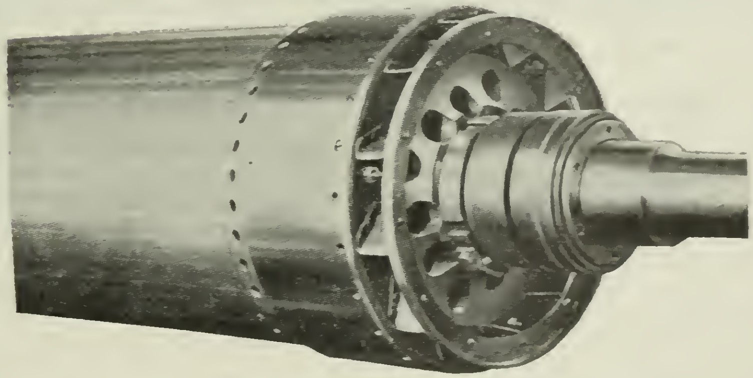
Cylindrical type of rotor with parallel slots. In this type the end connections *a* are well supported, but the bending stress at *b* becomes excessive at high speeds.

FIG. 58.



Cylindrical type of rotor with radial slots. There is no bending force on the teeth, but the support for the end connections is not as good as in Fig. 57.

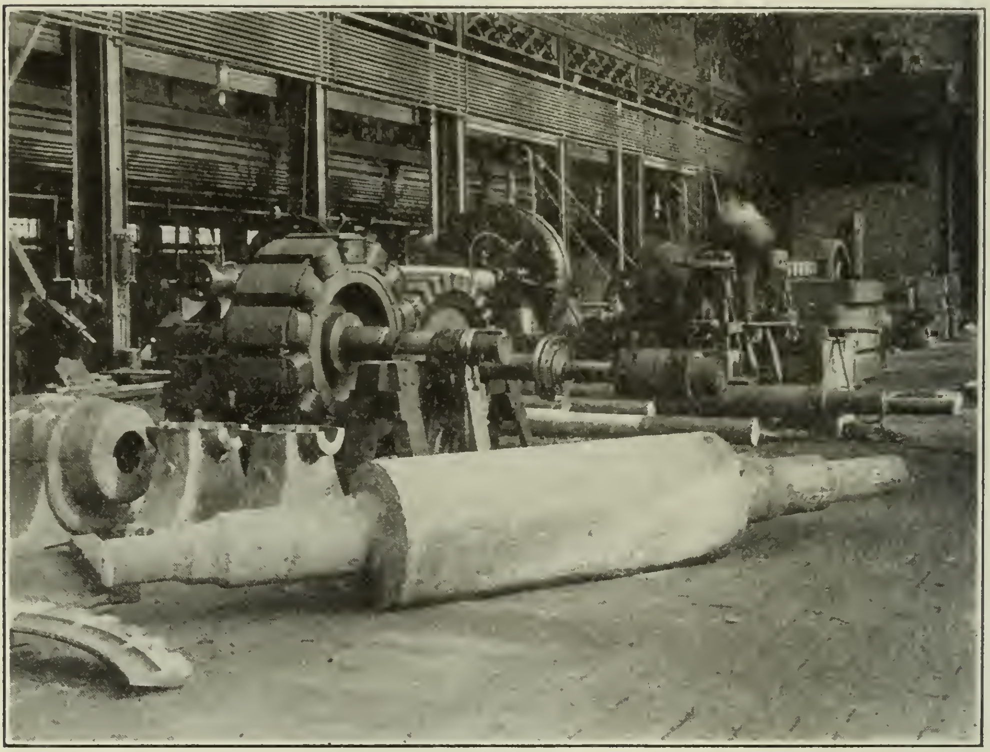
FIG. 58A



Part of the rotor of a 1250-kv.a., 3600-r.p.m. generator.

the more satisfactory because of the better utilization of the space in the rotor bore. Many of the different types of construction have been weeded out until we now have in this country only two that are used for machines of large output: in one case, shown in Figs. 59 and 60, the rotor is forged out of a solid block of steel which is carefully worked and annealed; in the other case it is built up out of plates that are rabbited into one another and held together by through bolts as shown in Fig. 61.[21]

FIG. 59.



Hydraulically forged rotor core and shaft for a 6250-kv.a., 3600-r.p.m. turbo-alternator.

A cylindrical rotor with radial slots is shown in Fig. 62 in process of winding. One of the most difficult problems with this type of construction is to support the rotor end connections. They are generally held against centrifugal force by a retaining ring as shown in Fig. 58. The stress in such a ring rotating with a peripheral velocity of 23,000 feet per minute at 1800 revolutions per minute is 15,000 pounds per square inch, due to its own weight, and, in order that the ring may support the end connections at 20 per cent. overspeed, it must be of high-grade steel, which material may be obtained in the form of a nickel chrome steel weldless ring with the following characteristics:

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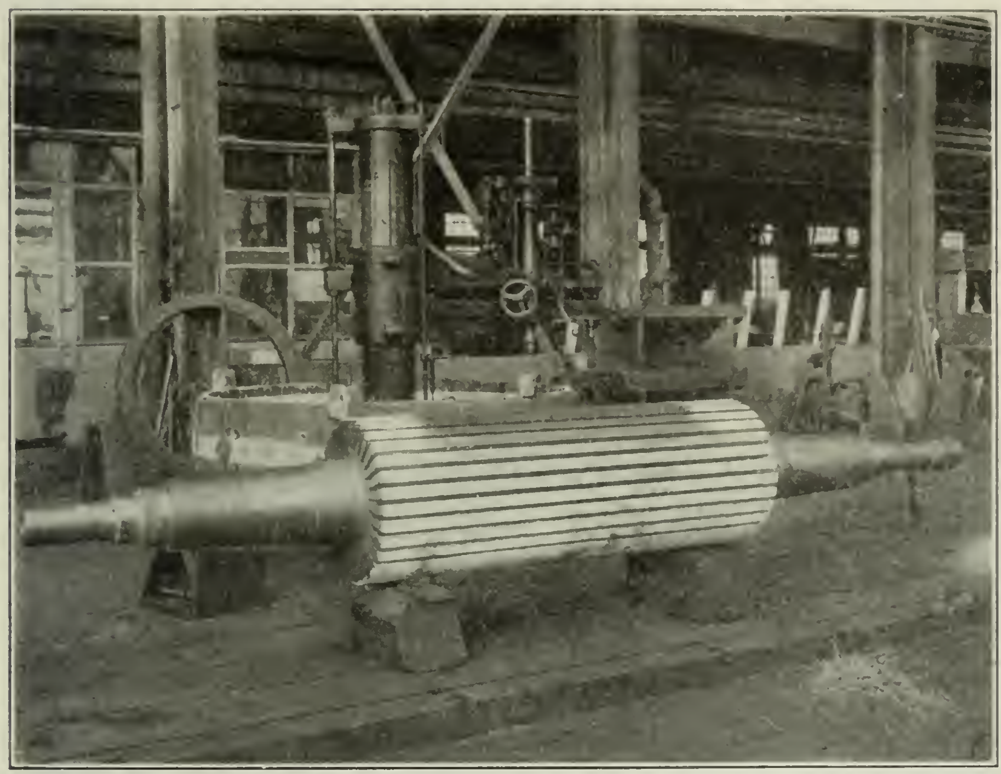
[21] "Some Difficulties of Design of High-speed Generators," Field, *Ibid.*, vol. 54, p. 65, 1915.

Ultimate stress = 120,000 pounds per square inch.
Elastic limit = 100,000 pounds per square inch.
Elongation = 18 per cent. on 2 inches.
Reduction in area = 50 per cent.

FIG. 60.



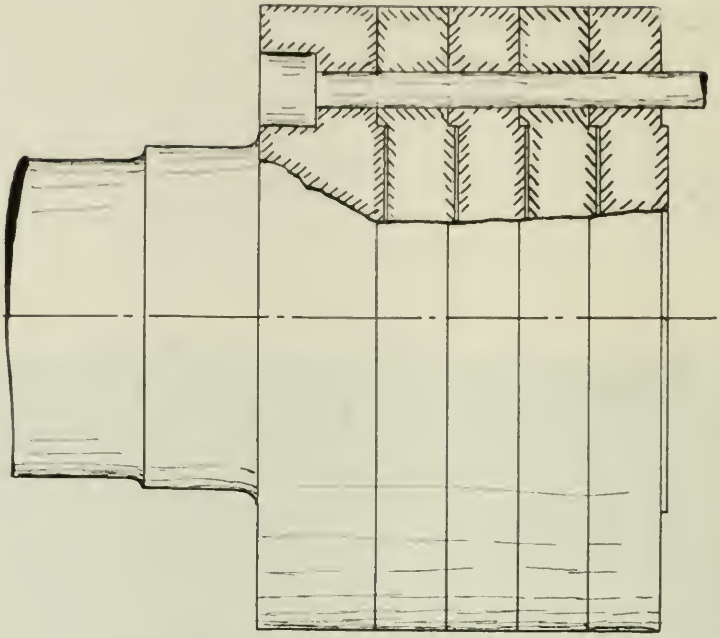
Rotor core of a 6250-kv.a., 3600-r.p.m. turbo-alternator.

It is true that by using steel for this purpose a magnetic shunt is placed between the poles, and the resulting leakage flux is limited only by the saturation of the material, so that the leakage factor would be large were it not for the fact that the poles are long and the useful flux per pole is large.

Limitations in Modern Turbo-Alternators.

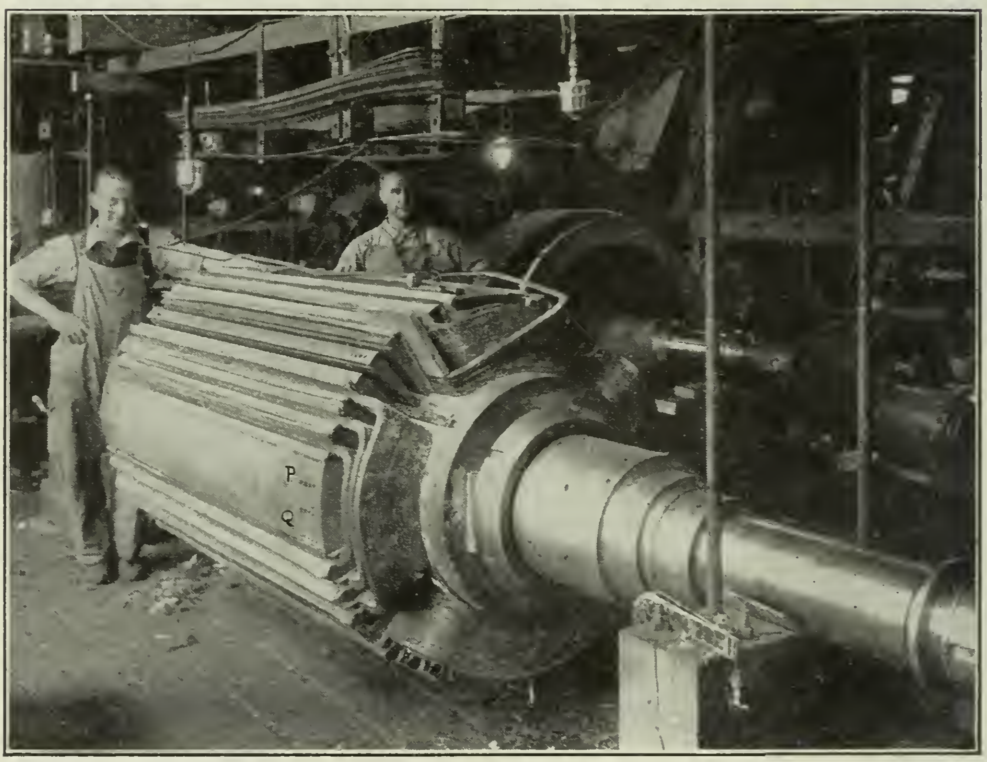
We have seen that the cylindrical type of rotor has proved by experience to be the most desirable for turbo-alternators of large output and high speed, and, in order to understand the develop-

FIG. 61.



Cylindrical rotor built up out of plates.

FIG. 62.



Rotor of a 12,500-kv.a., 1800-r.p.m., 60-cycle turbo-alternator.

ment that has taken place, we shall find the dimensions of a 60-cycle machine with an output of 30,000 kilovolt-ampères at 1800 revolutions per minute, and then show by how much the output would have to be reduced if the regulation and the permissible rise of temperature were as specified a few years ago.

Maximum Permissible Diameter of Rotor.—The subject of stresses in rotating disks that are loaded on the external periphery is very complex and is beyond the scope of this article.[22] Turbo-rotors have been built to run at 1800 revolutions per minute with a peripheral velocity of 24,000 feet per minute without the use of special steel, and, taking this as a suitable value, the diameter of the rotor for such a machine is 51 inches.

Width of Rotor Winding Belt.—It may be seen from Fig. 62

FIG. 63.

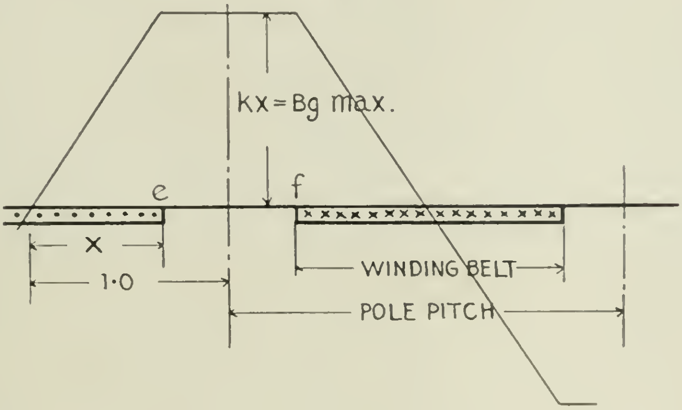
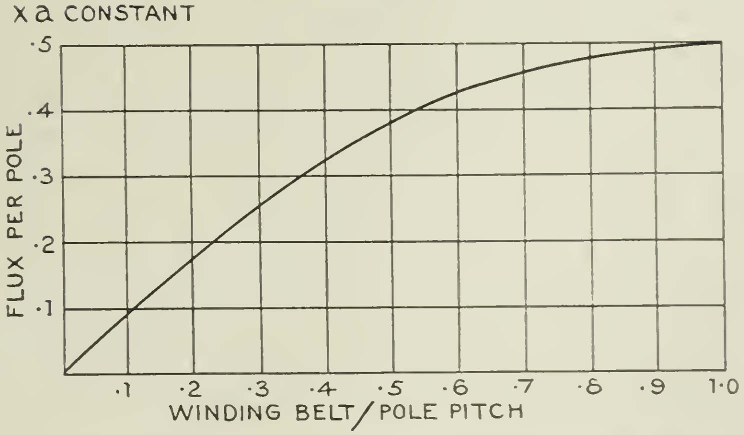


FIG. 64.



Effect of the width of the winding belt on the flux per pole.

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[22] "Design and Construction of Steam Turbines," by H. M. Martin, published by Longmans, Green & Co., in 1913.

that the whole rotor surface is not utilized to carry the rotor winding; there is still room for two more slots per pole at p and q and for one more coil. It will be noted, however, that this coil would span only a small part of the pole pitch, so that the additional flux produced per pole would not be worth the cost of the additional copper.

In Fig. 63 let the rotor be wound uniformly over a belt of width x and let the air-gap clearance be uniform; then the curve of flux distribution will be as shown, and

the flux density over the surface $ef = kx$

the total flux per pole $= \text{a constant } \left[x\ (1-x) + \frac{x^2}{2}\right]$

$= \text{a constant } \left[x\ \left(1-\frac{x}{2}\right)\right]$

This is the equation to the curve in Fig. 64, from which curve it may be seen that, for equal increments in the width of the winding belt, the corresponding increments in the flux per pole become gradually smaller, and that the addition of the last 30 per cent. of the rotor copper causes an increase of only 9 per cent. in the flux per pole. There is evidently a point, therefore, beyond which the gain in the flux per pole is not worth the price of the additional copper, and, judging from present practice, it would appear to be uneconomical to make the width of the belt greater than 70 per cent. of the pole pitch.

Maximum Depth of Slot.—Each tooth has to be strong enough to carry the centrifugal force due to its own weight and to that of the contents of one slot, so that if the depth of slot is increased its width will have to be decreased, as shown in Fig. 65, in order to leave enough metal at the root. For one particular value of the slot depth, the slot area $(s \times d)$ will have the largest value.

The stress at t, Fig. 65, is given by the formula: Stress in pounds per square inch $= \frac{(r1^3 - r2^3)}{21.5 \times 10^6 \times t} \times \frac{(t+s) \times 360}{2\pi r2}$ where the dimensions are in inches. If the diameter of the rotor is 51 inches, the speed is 1800 revolutions per minute, and the tooth stress is limited to 14,000 pounds per square inch; then the maximum slot width for each value of slot depth is as shown in Fig. 66; the variation of permissible slot area with slot depth is also shown, and in this particular case there is nothing to gain by using slots that are deeper than 7 inches.

Number of Slots per Pole.—Given that the rotor diameter is 51 inches, the winding belt covers 70 per cent. of the pole pitch, and the slot depth is 7 inches, let us find the number of slots

Fig. 65.

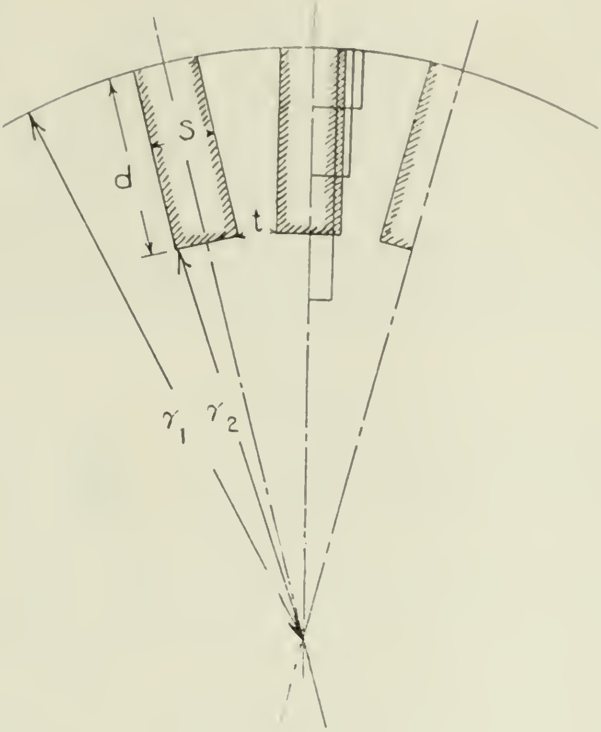
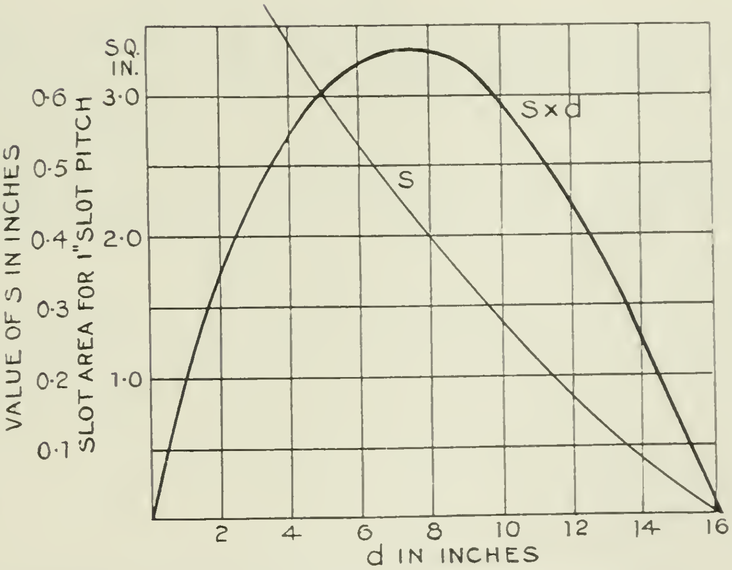


Fig. 66.

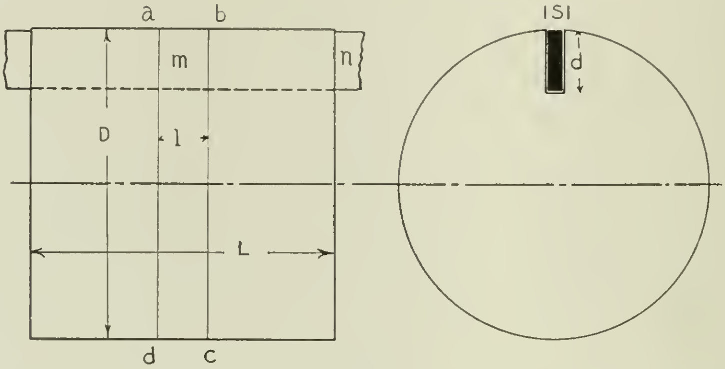


Variation of the slot area per pole with the depth of the slot.

that will give the largest excitation, the rise in temperature of the rotor copper being limited to 100° C.

The maximum slot area per pole may be obtained from Fig. 66, and this area is independent of the number of slots per pole. The part of this space that is occupied by insulating material increases with the number of slots per pole, because the thickness of the cell does not change; one can indeed conceive of the case where the number of slots is so large that the slots are not wide enough to hold more than the insulating cell, and the space for copper is zero. On the other hand, the copper loss per slot decreases as the number of slots is increased, and, as the heat generated has to pass through the insulation before it can be dissipated from the external surface of the rotor, the temperature drop through the insulation, being proportional to the heat generated per slot, decreases as the winding is subdivided, so that the current density can be increased. There is a point, however, beyond which the effect of the reduction in copper space more than compensates for the increase in the current density, and the problem is to find the number of slots per pole for which the ampère-turns per pole has the largest value.

FIG. 67.



A short digression will be necessary here to derive a formula for the temperature rise of the rotor copper. The assumption made in this discussion is that all of the heat generated in the part *a b c d* of the rotor, Fig. 67, is dissipated from the surface πDl, or that each part of the rotor gets rid of its own heat and there is no conduction axially along the winding. That this assumption is not unreasonable may be shown as follows:

If it is assumed that, since the copper is a good conductor of heat and is surrounded by insulating material which is a poor conductor, the heat generated in the copper is all conducted to and dissipated from the ends, then the difference in temperature between m and n, Fig. 67, is equal to

$$= \int_0^{L/2} (I^2 \times \frac{\rho x}{A}) \times \frac{dx}{A} \times \frac{1}{k}$$

where I is the current per conductor.

ρ is the resistance of a conductor 1 inch long and 1 square inch in cross-section $= 0.8 \times 10^{-6}$ ohms at normal operating temperatures.

k is the thermal conductivity of a conductor 1 inch long and 1 square inch in cross-section = 11 watts per 1° C.

therefore

$$T_{mn} = \frac{\rho}{k} \frac{I^2}{A^2} \frac{L^2}{8} \text{ deg. Cent.}$$

A reasonable value for I/A, the ampères per square inch, is 1950 (650 circular mils per ampère), and for L is 60 inches, and for these conditions $T_{mn} = 125°$ C.

If, on the other hand, we assume that all of the heat is conducted through the insulation, then the heat generated per inch length of slot is equal to

$$\frac{\text{conductors per slot} \times (\text{current per conductor})^2 \times \rho_1}{\text{cross-section of conductor}}$$

$$= \frac{\text{ampère conductors per slot}}{\text{circular mils per ampère}} \times 1.0$$

since ρ_1, the resistance of a conductor 1 inch long and 1 circular mil in cross-section, is equal to 1 ohm approximately at normal operating temperatures.

The temperature drop through the insulation is equal to

$$\frac{\text{ampère conductors per slot}}{\text{circular mils per ampère}} \times \frac{\text{thickness of insulation}}{2 \times \text{slot depth}} \times \frac{1}{K}$$

where K, the thermal conductivity of insulating material in inch units, is 0.003 watt per degree Centigrade.

For a turbo-rotor with 51,000 ampère turns per pole,
10 slots per pole,
650 circular mils per ampère,
0.1 thickness of insulation in inches,
5.75 effective slot depth in inches,
the temperature drop through the insulation is 45° C.

The difference in temperature, Tr, between the rotor copper and the air which enters the machine is equal to $T_a + T_b + T_c$ where T_a = the difference in temperature between the copper and the iron, which, as already shown, is equal to

$$\frac{\text{ampère conductors per slot}}{\text{circular mils per ampère}} \times \frac{\text{thickness of insulation}}{2 \times \text{effective slot depth}} \times \frac{1}{0.003}$$

The thickness of insulation is generally 0.1 inch.

T_b = the difference in temperature between the iron and the air at the rotor surface is equal to

$$\frac{\text{watts loss per inch length of slot} \times \text{total slots}}{\pi D} \times K_r$$

where K_r is the temperature rise per watt per square inch of the rotor surface and has a value of about 10 degrees Centigrade for surface velocities of the order of 20,000 feet per minute, therefore

$$Tb = \frac{\text{ampère conductors per slot}}{\text{circular mils per ampère}} \times \frac{10 \times \text{slots per pole}}{\text{pole pitch}}$$

T_c = the difference in temperature between the air at the rotor surface and that entering the machine, a reasonable value for which is 15° C.

$$\text{therefore } T_r = \frac{\text{ampère conductors per pole}}{\text{circular mils per ampère}} \left[\frac{33}{(2d) \text{ slots per pole}} + \frac{10}{\text{pole pitch}} \right] + 15$$

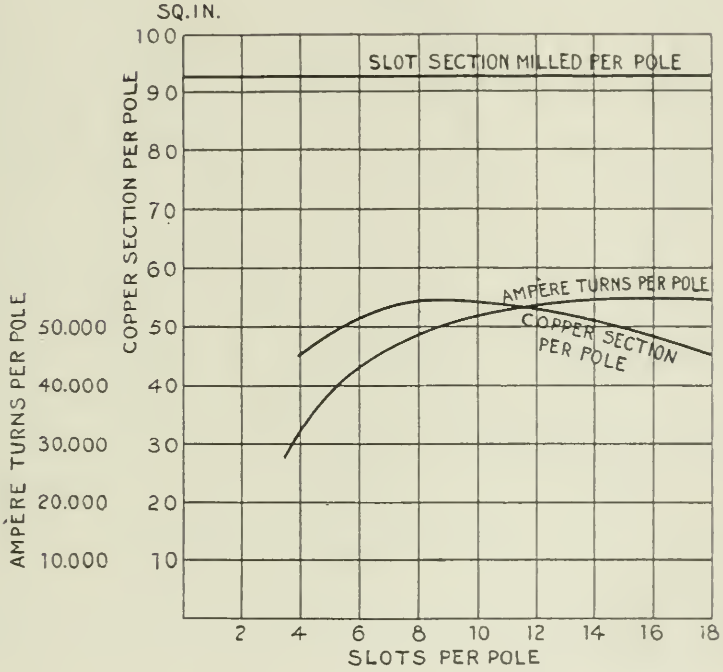
We are now in a position to find the most suitable number of slots per pole given that the rotor diameter is 51 inches, the winding belt is 0.7 times the pole pitch, or 28 inches, the slot depth is 7 inches, the stress in the rotor teeth is 14,000 pounds per square inch, and the permissible value of T_r is 100° C.

Slots per pole	Slot depth Inches	s, Fig. 65 Inches	t, Fig. 65 Inches	Depth of wedge = f Inches	Copper section per slot = (d-f-0.3) s-0.2) × 0.85 Square inches
4	7	3.34	1.76	2.6	10.90
6	7	2.21	1.17	1.75	8.46
8	7	1.66	0.88	1.3	6.70
10	7	1.33	0.70	1.25	5.22
12	7	1.11	0.59	1.25	4.22
16	7	0.83	0.44	1.25	2.92
20	7	0.66	0.36	1.25	2.13

$\frac{10}{\text{Pole pitch}}$	+	$\frac{33}{2d \times \text{slots per pole}}$			$\frac{\text{Ampère conductors per pole}}{\text{Circular mils per ampère}}$
0.25	+	0.94	=	1.19	71.5
0.25	+	0.52	=	0.77	110
0.25	+	0.36	=	0.61	139
0.25	+	0.29	=	0.54	157
0.25	+	0.24	=	0.49	173
0.25	+	0.18	=	0.43	197
0.25	+	0.144	=	0.394	215

Ampère turns per pole, Fig. 68	Circular mils per ampère
31400	880
42000	760
48700	700
51000	650
52700	610
54000	550
54000	500

FIG. 68.



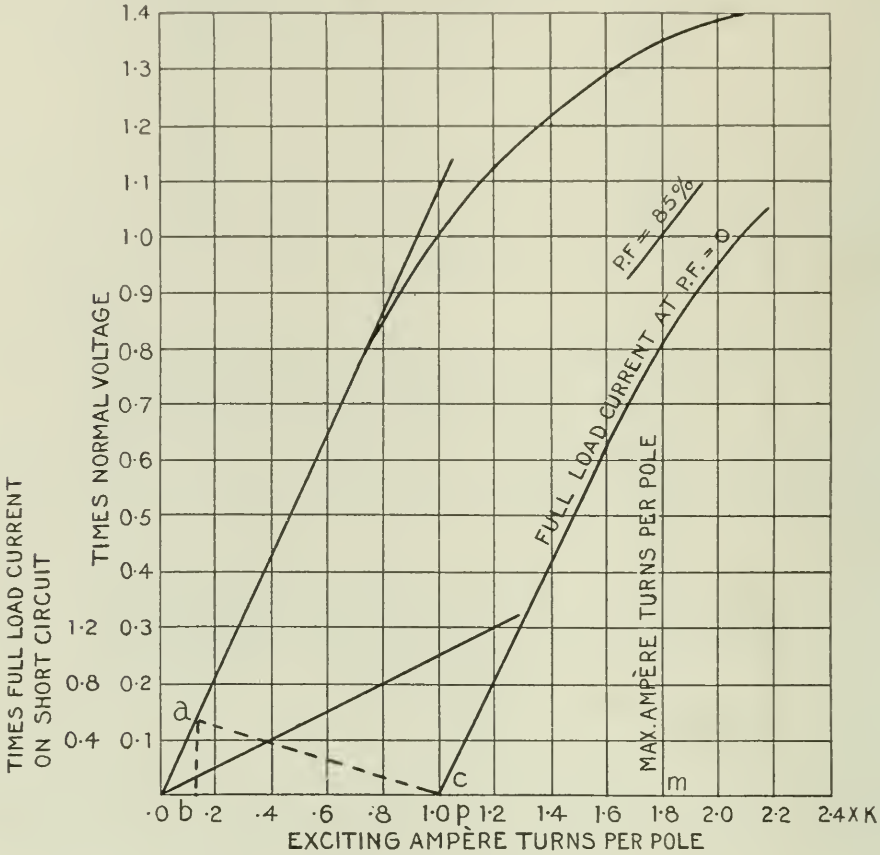
Effect of the number of rotor slots per pole on the maximum excitation.

The depth of the wedge can be decreased as the slot width is decreased, but in this particular machine it cannot be made less than 1.25 inches, because the projecting rotor coils have to be supported by a retaining ring whose thickness *y*, Fig. 58, must be sufficient to support the total weight of end-connection copper, and this weight is almost independent of the number of slots per pole.

The copper section per slot was found by assuming that the cell of slot insulation is 0.1 inch thick and that the insulation between layers occupies 15 per cent. of the available space.

Armature Ampère Turns per Pole at Full Load.—Fig. 69 shows typical characteristic curves of a modern alternator of large capacity. The air-gap clearance has such a value that the field excitation required to give normal voltage on no-load (namely, *op*) is just sufficient to cause full-load current to circulate in the armature on short circuit.

FIG. 69.



Characteristic curves of a modern alternator.

The leakage reactance drop = *ab*.

= 14 per cent. of normal voltage.

The demagnetizing ampère turns per pole = *bc*.

= 0.48 (om).

= 0.48 (maximum field ampère turns per pole).

This quantity is also[23] = 0.41 (armature ampère turns per pole × 2)

therefore armature ampère turns per pole

= 0.59 (maximum ampère turns per pole).
= 0.59 × 51,000 with 10 slots per pole, Fig. 68.
= 30,000.

The corresponding value of ampère conductors per inch of stator periphery is approximately 1440.

Generated Voltage per Conductor.—If the rotor and the stator teeth are not highly saturated then, since the air-gap clearance is large, the flux distribution over the pole pitch is as shown in Fig. 63, and, for a winding belt of 70 per cent., the average gap density is 0.65 times the maximum value. If, then, the stator tooth density is limited to 100,000 lines per square inch, the flux per pole

$$\Phi = 100{,}000 \times \frac{t}{t+s} \times \text{pole pitch} \times L_n \times 0.65$$

where L_n is the net length of iron in the core,
t is the width of stator tooth tip,
s is the width of stator slot.

The value of t/s will not exceed 1.10 for a 13,200-volt machine.

The effective electromotive force per conductor is

$$\begin{aligned} Ec &= 2.22 \times \Phi \times \text{frequency} \times 10^{-8} \\ &= 2.22 \times \left(100{,}000 \times \frac{1.1}{2.1} \times \frac{\pi \times 53}{4} \times Ln \times 0.65\right) \times 60 \times 10^{-8} \\ &= 1.88\, Ln \text{ for this particular machine.} \end{aligned}$$

The Maximum Output.—The maximum permissible output for a machine is

$$KV.A. = k_b \times E_c \text{ ampère conductors per pole} \times \text{poles } 10^{-3}$$

where k_b, the winding distribution factor, is equal to 0.96 for a full-pitch, three-phase winding, therefore

$$\begin{aligned} KV.A. &= 0.96 \times (1.88\, L_n) \times (30.000 \times 2) \times 4 \times 10^{-3} \\ &= 432 \text{ per inch length of net iron.} \end{aligned}$$

The net core length for a 30,000-kv.a. machine is therefore equal to 70 inches.

Stator Ventilation.—Many schemes have been suggested and used for the cooling of turbo-alternators. In modern practice the machine is totally enclosed and air is forced through and directed on to the surfaces to be cooled. About 100 cubic feet of air is required per minute per kilowatt of loss, and this will cause the air to rise 18° C. in passing through the machine.

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[23] "Electrical Machine Design," Gray, p. 289.

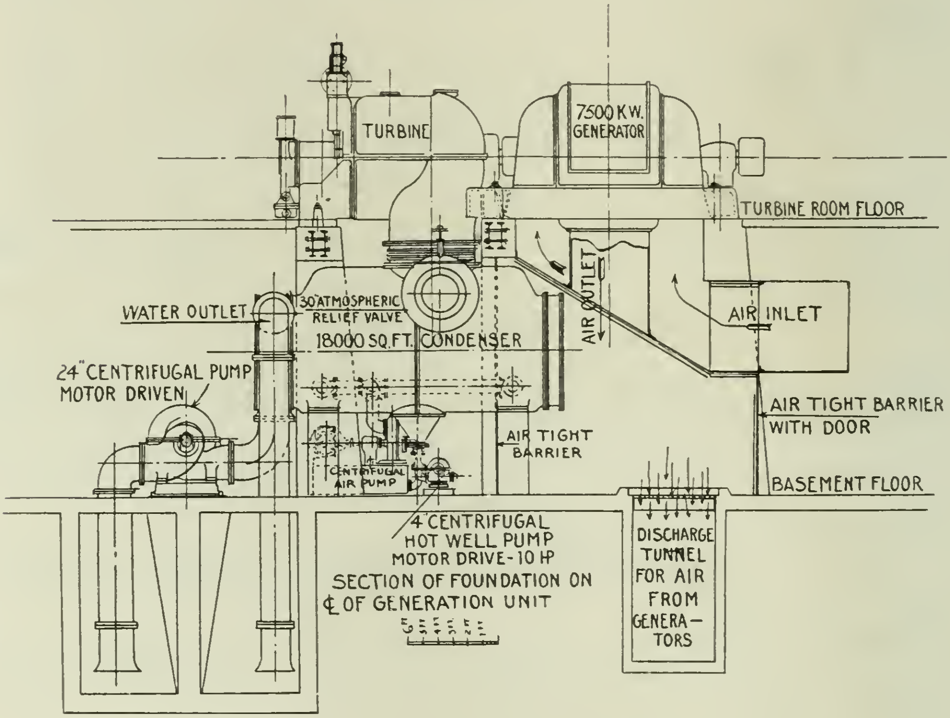
A turbo-alternator with a capacity of 30,000 kv.a. will have a loss on full load at 85 per cent. power factor of about 760 kilowatts, distributed approximately as follows:

Stator I^2R .... = 37
Core loss .... = 230
Stray loss .... = 100
367
Rotor I^2R .... = 68
Windage, friction and fan .... = 325

Total .... = 760

This machine will therefore require about 76,000 cubic feet of air per minute, which is the contents of a room 10 feet cube emptied about 1¼ times every second. This large volume of air should not be drawn from the power-house and then discharged

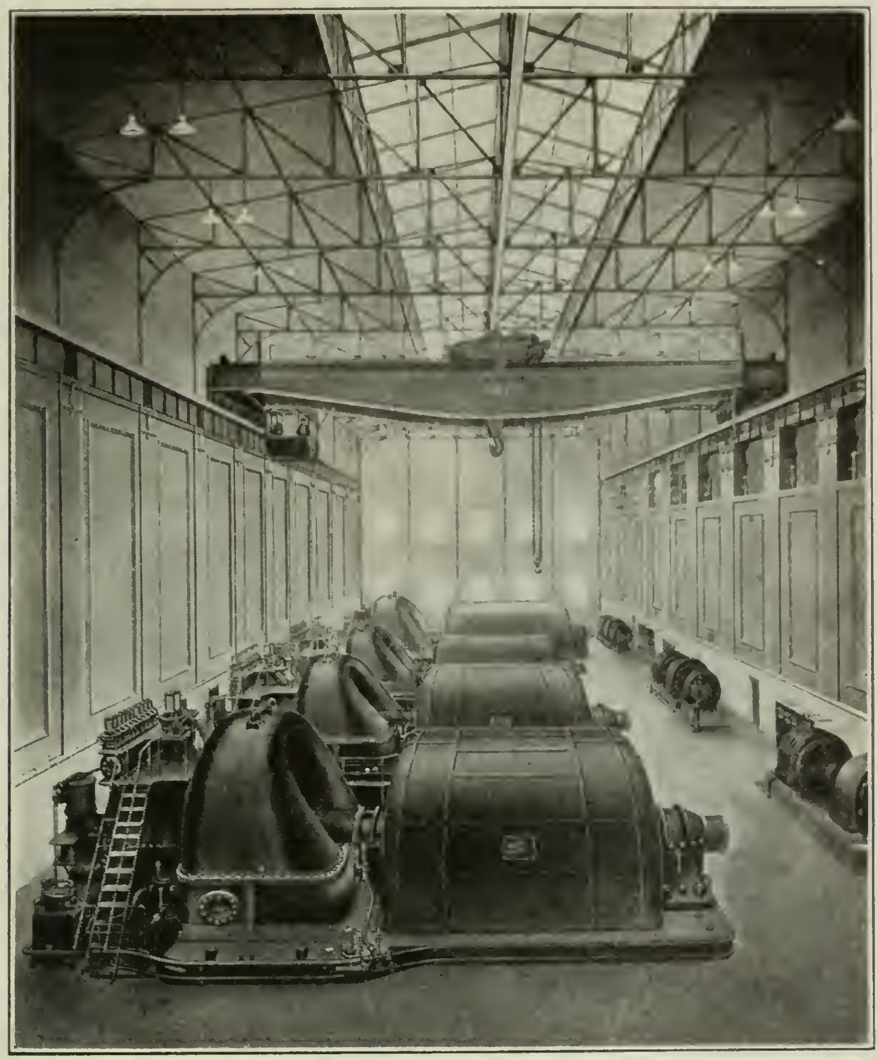
FIG. 70.


TURBINE
7500 KW. GENERATOR
TURBINE ROOM FLOOR
AIR OUTLET
AIR INLET
WATER OUTLET
30" ATMOSPHERIC RELIEF VALVE
18000 SQ. FT. CONDENSER
24" CENTRIFUGAL PUMP MOTOR DRIVEN
AIR TIGHT BARRIER WITH DOOR
AIR TIGHT BARRIER
CENTRIFUGAL AIR PUMP
BASEMENT FLOOR
4" CENTRIFUGAL HOT WELL PUMP MOTOR DRIVE - 10 HP
SECTION OF FOUNDATION ON ℄ OF GENERATION UNIT
DISCHARGE TUNNEL FOR AIR FROM GENERATORS

Air-ducts for a turbo-alternator.

back again, because it rises 18° C. every time it passes through the machine. It is considered good practice to draw the air from outside of the building, pass it through air washers, and then through the machine, after which it is discharged outside of the

FIG. 71.



Turbine room, river station, Buffalo General Electric Company.

building by a suitable duct. Such a scheme of ventilation is partly shown in Fig. 70. The appearance of the station is then as shown in Fig. 71.

This large volume of air must be brought into close contact with the heated surfaces, and the two best-known methods of accomplishing this result are indicated in Fig. 72. In one case the air is forced through axial ducts across the edges of the laminations, and in the other case radial ducts are provided. In the former case the duct surface is 150,000 square inches, and in the latter case 200,000 square inches are provided, so that the watts of stator loss per square inch of stator duct surface are 2.45 and 1.83 respectively; the higher value can be used with the axially ventilated machine, because the temperature drop through the iron part of the heat path is lower than in the machine with the radial ducts, because, in this latter case, the heat has to flow across the laminations.

FIG. 72.

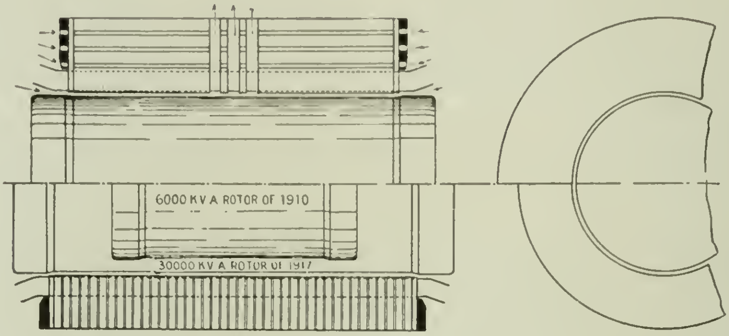
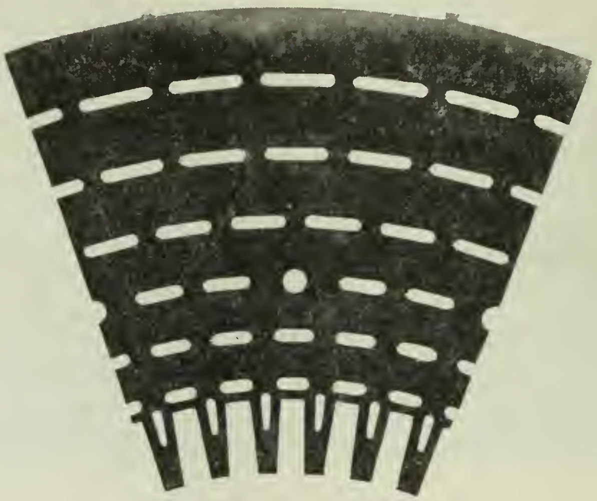


Diagram showing axial and radial ventilation of a 30,000-kv.a. turbo-alternator

FIG. 73.

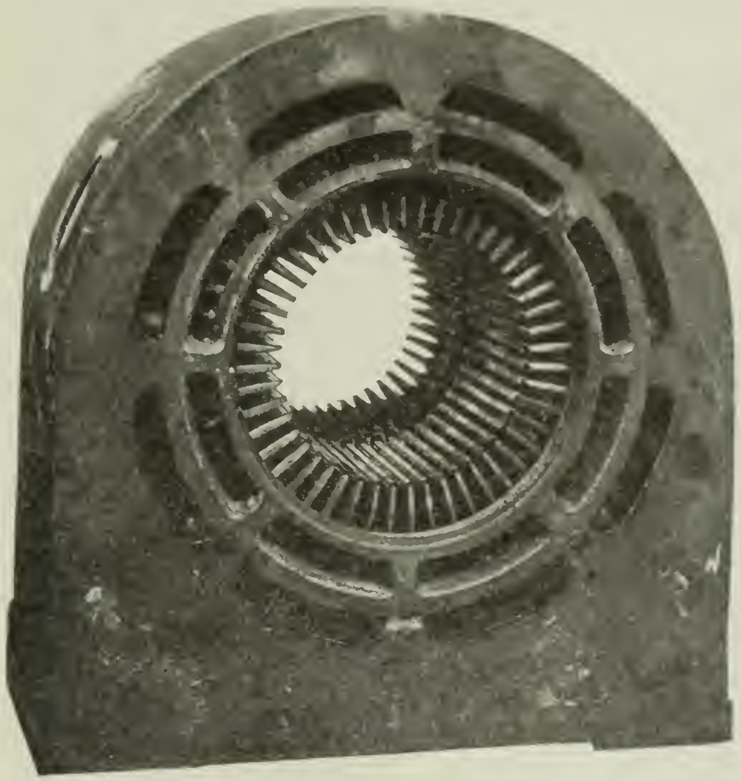


Stator punching of an axially ventilated machine.

Stator Construction.—Fig. 73 shows one of the punchings of an axially ventilated stator. The duct surface must be sufficient to limit the watts per square inch to about 2.45 and the duct section such as to limit the air velocity to 5000 feet per minute, with an air supply of 100 cubic feet per minute per kilowatt of total loss.

Fig. 74 shows the stator assembled and ready to be wound; the air passes axially as shown in Fig. 72 and escapes through the central duct. Fig. 75 shows a machine of greater output, the volume of air being such that three central ducts are required for its escape. The stator winding, it will be noted, is thoroughly braced on the ends so that it will be able to withstand the enormous mechanical forces that are exerted when the machine is suddenly short-circuited.[24]

FIG. 74.



Stator of an axially ventilated turbo-alternator.

The first method of cooling turbo-alternators by means of radial ducts was that covered by the Brown patents of 1901 and is shown diagrammatically in Fig. 76. This method is still used for machines up to about 1000 kv.a. capacity. Air from the rotor fans is forced into the chamber *B*, whence it passes up both sides of the machine in parallel. In the case of larger machines, however, the length of path *c* becomes excessive and it becomes difficult to keep the top of the machine cool. This difficulty is overcome by introducing cool air at several points on the stator periphery, as at *A*, Fig. 77.

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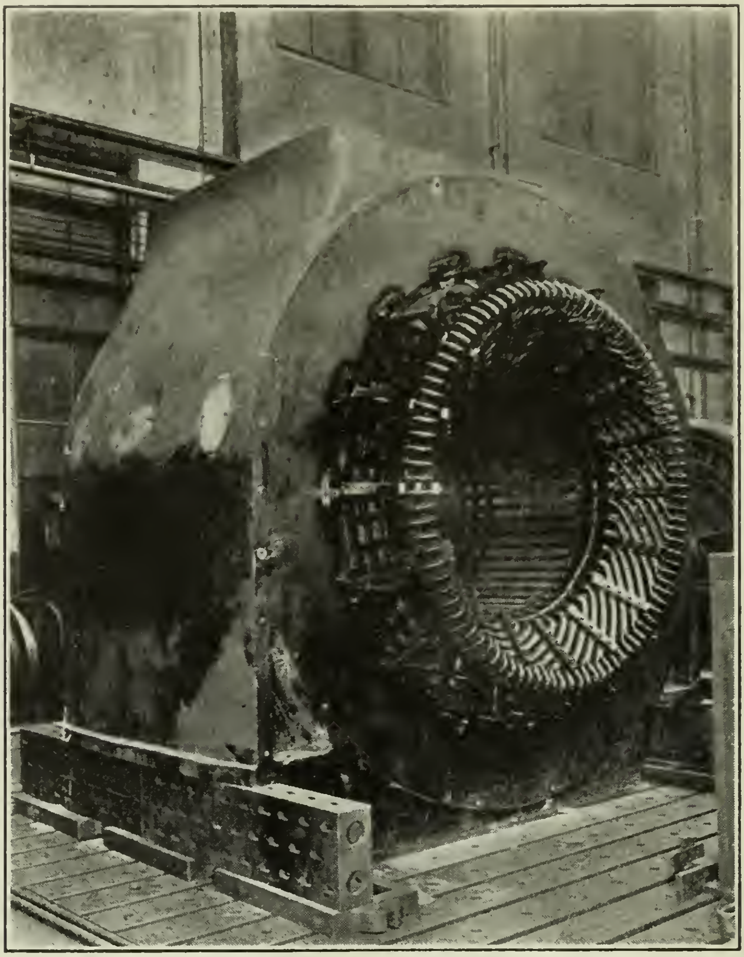
[24] "Short-circuiting of Large Electric Generators and the Resulting Forces on the Armature Windings," Walker, *Journal of the Institution of Electrical Engineers*, vol. 45, p. 295, 1910.

FIG. 75.

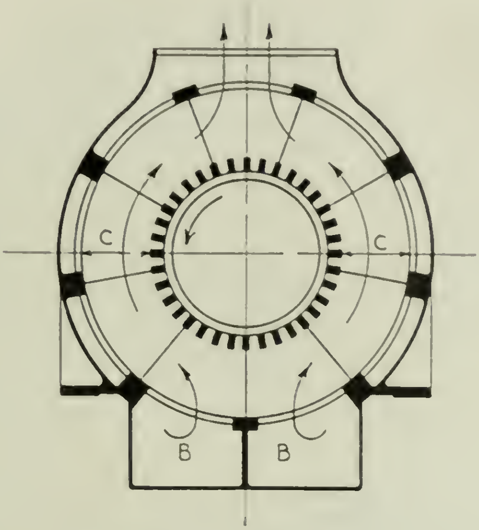


Stator of an axially ventilated turbo-alternator.

Fig. 78 shows the stator core for such a machine. Air from the rotor fans passes to the openings *A* and then through the radial vent ducts to the exits *B*. Fig. 79 shows the same machine supplied with its winding, which again is thoroughly braced.

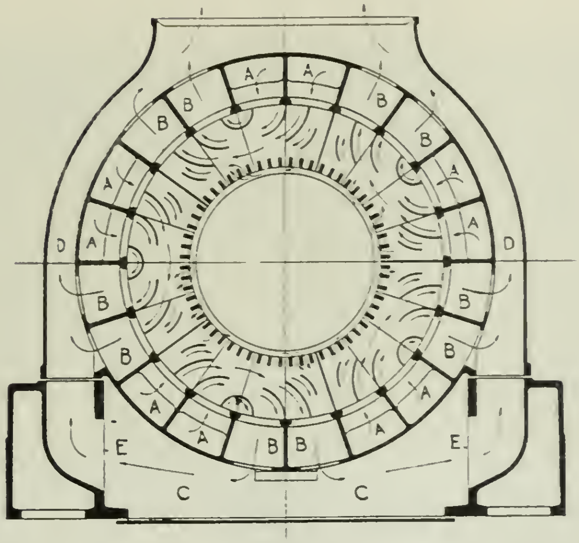
One other method of cooling used in this country makes use of the radial ducts, but these are fed from the air-gap as shown in Fig. 80 rather than from the outer periphery of the stator. When the ducts of a very long machine are fed in this way the velocity of the air in the gap becomes very high, and when it reaches a value of about 12,000 feet per minute it becomes desirable to feed the air-gap from the centre as well as from the ends of the machine, additional fans being added to the rotor for this purpose. Such a rotor is shown in Fig. 81.

FIG. 76.



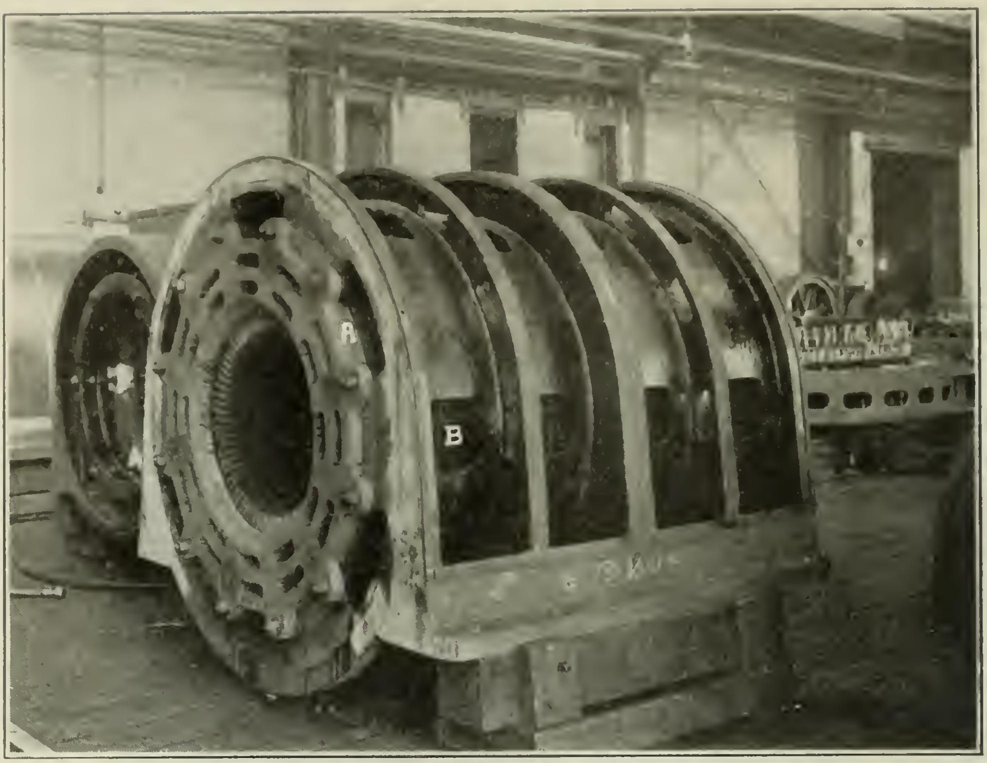
Ventilation of small turbos.

FIG. 77.



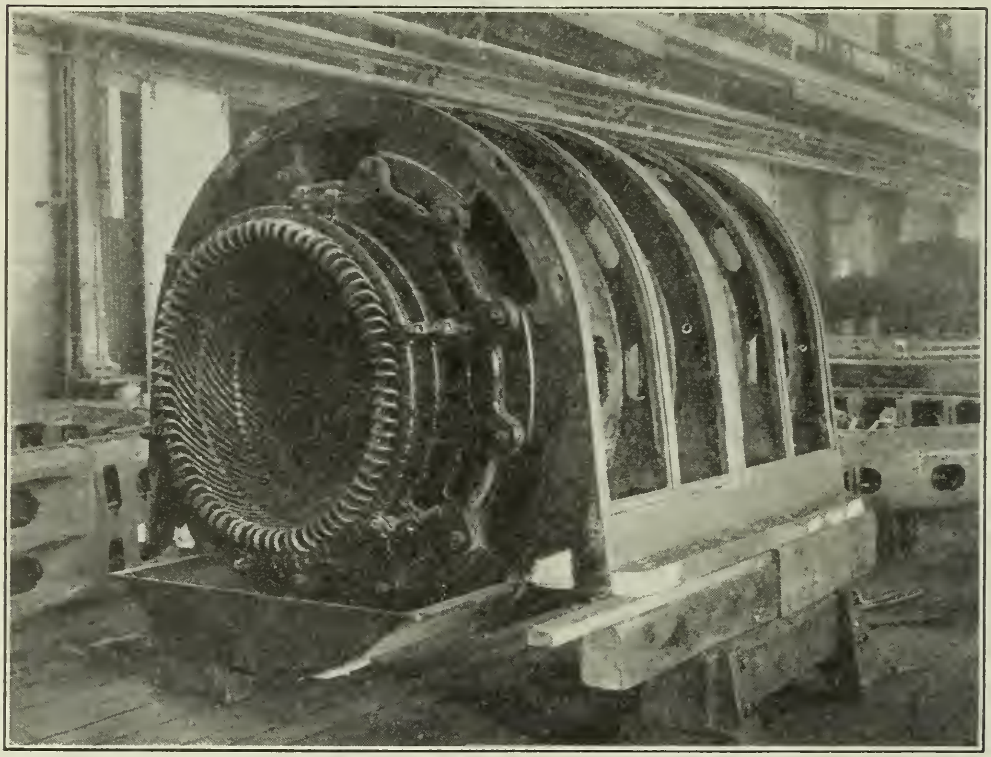
Turbo ventilation by means of radial ducts.

FIG. 78.



Stator core for a machine ventilated as shown in Fig. 77.

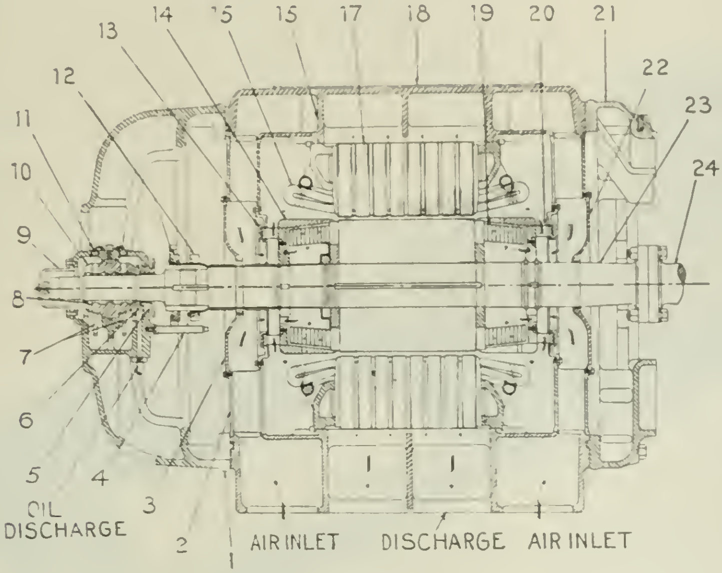
FIG. 79.



Stator for a machine ventilated as shown in Fig. 77.

In the 30,000-kv.a. machine under discussion the total loss on full load is 760 kilowatts, the volume of air required is 76,000 cubic feet per minute, the air-gap clearance is 1.75 inches, and the area of the air-path along the gap is 2 square feet, so that, if the machine is fed only from the ends, the maximum air velocity will be 19,000 feet per minute, but will have only half of this value if air is also fed into the gap from the centre of the machine. If the air is uniformly distributed to the ducts the maximum air velocity in the ducts will be less than 3000 feet per minute, except where the air passes through the ducts in the teeth. The velocity of the air is therefore high and the ventilation most effective in the air-gap and tooth ducts, and these are the places around which the losses are most concentrated.

FIG. 80.



Small turbo-alternator with air-gap ventilation.

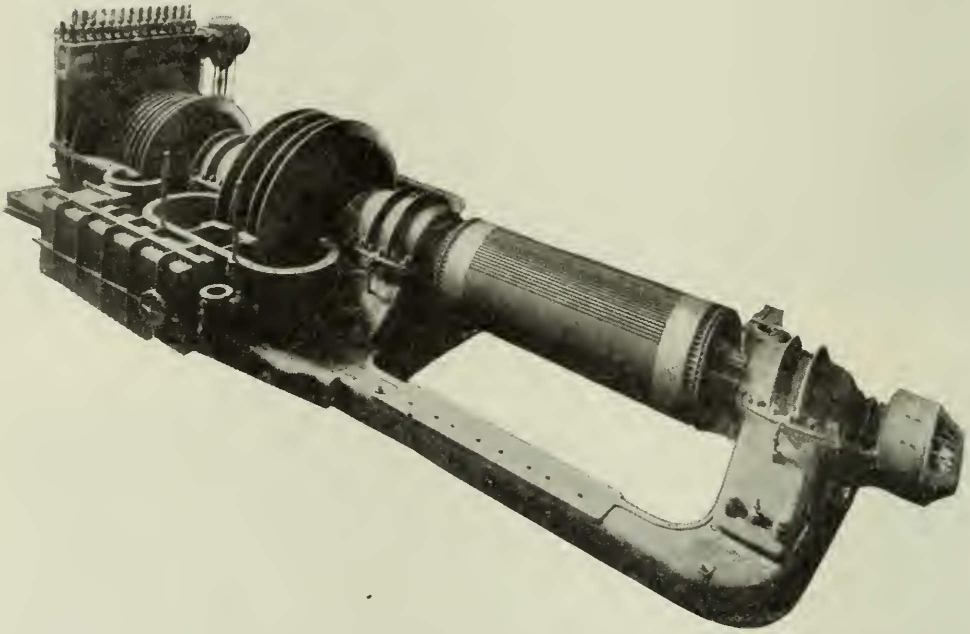
1. Outboard bearing bracket and cap. 2. Air shield. 3. Air-shield ring, outer (generator end). 4. Brush holder stud. 5. Oil deflector. 6. Oil fan. 7. Oil rings. 8. Cooling water tube. 9. End cover. 10. Lining. 11. Sight-hole plug. 12. Collector rings. 13. Air-shield rings (inner). 14. Field-retaining ring. 15. Armature coils. 16. Armature spider. 17. Armature punchings. 18. Lagging for armature spider. 19. Field coils. 20. Air fan and end flange. 21. Main bearing, cap, and connection piece. 22. Air-shield ring, outer (turbine end). 23. Shaft and revolving field. 24. Turbine half coupling and shaft.

All three of these solutions of the cooling problem are successful in practice. This is made certain by the insertion of thermocouples or resistance thermometers into the machine so that the temperature rise of the hottest part may be determined at any time. This temperature rise we have limited to 100° C. in the case of the rotor, and this value set a limit to the permissible rotor excitation and therefore to the stator ampère turns per pole.

Although the number of the stator conductors has therefore been fixed, their cross-section depends on the permissible temperature rise of the stator. If the coils are insulated with varnished cloth and mica, the maximum temperature should not exceed 100° C. as measured by a thermocouple. If, on the other hand, what is called a fire-proof insulation is used, this maximum temperature may have a value of 140° C., although operating engineers are not all prepared to run machines as hot as this.

Let us then compare two stators, one with a rise of temperature of 75° C. and the other with a temperature rise of 100° C., which are reasonable figures if the air is passed through an air-washer and enters the machine with a temperature of 25° C.

FIG. 81.



35,000-kw., 1200-r.p.m. Curtis steam turbine. The inner fans feed the air-gap from the ends and the outer fans feed it from the centre of the core.

In the high-temperature stator the current density is 15 per cent. greater, the slot is 15 per cent. shallower, and the temperature gradient through the insulation is 32 per cent. greater than in the low-temperature stator. The flux density in the core is increased 10 per cent., the duct surface is decreased 10 per cent., the core loss is increased 20 per cent., and the temperature drop at the duct surface is increased 32 per cent. The difference between the two stators is therefore that the low-temperature machine has 15 per cent. more stator copper, 10 per cent. more stator iron, smaller loss, and higher efficiency, while the rotor is the same for each machine.

The effect of desired voltage regulation on the output was discussed in the previous article. The maximum excitation, *om*, Fig. 69, is fixed in the case of a turbo-alternator, and the regulation can be improved only by a reduction in the reactance drop *ac* and in the armature reaction *bc*, and this can be accomplished only by a reduction in the armature ampère turns per pole and a corresponding reduction in the output. Fig. 72 shows the dimensions of a 6000-kv.a., 1800-r.p.m. machine with a rotor built for a maximum temperature rise of 100° C. with full-load current at zero power factor and for a regulation of 25 per cent. at 85 per cent. power factor.

Outputs greater than those at present obtained from a given frame are possible, provided the regulation is still further sacrificed and the temperature rise further increased.

(*To be continued.*)

Car Nosing. S. A. BULLOCK. (*Electric Railway Journal,* vol. 50, No. 4, p. 149, July 28, 1917.)—Car nosing, which is horizontal oscillation of the car body about instantaneous axes, occurs on tangent track and is usually negligible on curves. In passenger service a slight amount of nosing is preferable to the rigid transverse shock of non-swinging bolsters, but when these oscillations become excessive, nosing becomes a question of serious moment. The initial cause of nosing is poor track; that is, low joints and irregular gauge, which force the wheels to slide horizontally, producing a horizontal force at the wheel. This horizontal blow is transmitted through the axle to the various members of the truck, and finally to the car body.

Theory and practice both prove that nosing is reduced with long distances from centre to centre of king-pins and with heavy passenger loads. Nosing can be minimized by the following expedients: (1) Improvement of track conditions by levelling the low joints, keeping normal track gauge, and using proper weight of rail. (2) Reducing lateral play in the transverse moving parts by renewal of worn pieces, and breaking up synchronism of the movements by variable damping of the transverse motions in the front and rear trucks. (3) Reducing the overhang of the car body by lengthening the distance, centre to centre, of king-pins and reducing the overhang of the motors by placing the motors inside of the wheels.

A Cuprous Oxide Photo-chemical Cell. T. W. CASE. (*Proceedings of the American Electrochemical Society*, May 2–5, 1917.)—A large amount of work has been done on cells that produce an electromotive force on exposure to light. Becquerel, the pioneer in this field, and later Minchin and others, found that a large number of combinations could be developed that would produce a current under the influence of light. They worked out in detail a number of light-active cells consisting of silver salts upon some metal plate, and in these they observed certain peculiar reversals of current which they were unable to explain. These difficulties were later studied by Wildermann, who worked out equations applying to the action of photo-chemical cells, starting with the fundamental conception "that the chemical potential of a substance in light and dark is different, becoming greater in light."

In nearly all these photo-chemical cells the output was very small (ampères in units of 10^{-9} and volts in units of 10^{-6}). This, together with the unsatisfactory action, the ultimate consumption of the elements, and the difficulty of accurate observation of the actual processes taking place due to complicated side reactions, has tended to check research in this field. Since, however, the more photo-chemical reactions that are known, with their different modes of action, the more chance we have to understand the phenomena, the author has undertaken a search for new substances and combinations which show a voltage effect in light.

A systematic search was begun in the first instance with copper salts. A large number of electrolytes were found which would deposit a light-active coating upon copper, probably due to the formation of a copper oxide or halide salt upon the electrode. A copper formate electrolyte, containing free formic acid, using highly polished copper electrodes, was studied closely. If one plate be illuminated and the other kept dark, a current is produced, the illuminated plate being anode, and developing an electromotive force up to 0.11 volt. The current finally drops to zero; but if the cell is rotated, illuminating the previously dark plate, the electromotive force reappears. On continued rotation the electromotive force reaches a maximum value. Below a critical light intensity the cell gives very little response.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

THE LATENT HEAT OF VAPORIZATION OF AMMONIA.

By Nathan S. Osborne and Milton S. Van Dusen.

[ABSTRACT.]

The latent heat of vaporization of liquid ammonia has been determined throughout the temperature interval −42° to + 52° C. by direct measurements, using a calorimeter specially designed for the particular problem. This instrument is of the aneroid or unstirred type, the ammonia being the only liquid in the calorimeter. Heat developed and measured electrically in a coil is transmitted by conduction and convection to the ammonia, and is expended in the evaporation of a determined amount which is withdrawn as superheated vapor. Accessory data from other sources are required only in the computation of small correction terms. The results are expressed by an empirical equation and a table of values given for every degree from −45° C. to + 55° C. By combining the data for the heat of vaporization with the data for specific heat of the saturated liquid from a previous investigation, the specific heat of saturated ammonia vapor is obtained and a table of values of this quantity is given in an appendix.

MAGNESIA IN PORTLAND CEMENT.

[ABSTRACT.]

In order to determine what new constituents are produced in Portland cement, when the magnesia content is raised considerably above that permitted by present standard specifications, and in order further to determine what effect these new constituents would have upon the physical properties of the material, a number of cements were burned in the rotary kiln of the Bureau. In these the magnesia content varied from 1.7 per cent. to 25.5 per cent. In all 18 different cements were produced in two series of nine burnings each. In both series the compositions were those of normal cement, excepting the magnesia content only.

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* Communicated by the Director.

But in one case the silica content was somewhat higher and the alumina content somewhat lower than in the other case.

As raw materials, clay, kaolin, feldspar, limestone, and dolomite were used. In the one series, the cement of lowest magnesia content was made of a raw mix containing limestone, clay, and a small amount of feldspar, the latter being added to increase the silica-alumina ratio over that obtainable with clay and limestone alone. The magnesia in the other burns of this series was increased by replacing the limestone with dolomite. In the second series the raw mixes were composed of clay, limestone, and a small amount of kaolin, the latter being used to decrease the silica-alumina ratio over that obtainable with the clay alone. In this series, also, increasing amounts of limestone were replaced with dolomite, until dolomite alone was used.

The deportment of the high magnesia cements in the kiln was very characteristic. There was a reduction of the clinkering temperature with increasing magnesia content, though to produce satisfactory clinker this was not as marked as expected. But to prevent the dusting of the clinker of the higher magnesia content cements it was necessary to overburn to a very hard, vitreous mass. This mass in the kiln was about of the consistency of putty, and as a result there was a decided tendency to form "logs" and "rings." The clinker was also of a reddish-brown color, which gave a decided brownish tinge to the ground cement.

A microscopical examination of the clinker showed that increasing amounts of magnesia produced an increasing size of crystals and granularity. When the magnesia exceeded 8 per cent., a constituent (monticellite) not present in normal cement was noted. When the magnesia was still further increased to an amount exceeding 10 per cent., another constituent—spinel—not present in normal cement, was also noted. It was also noted that those constituents—tricalcium silicate and tricalcium aluminate—which produced quick setting and early strength, were not materially decreased by the appearance of the new constituents; whereas, the orthosilicate of lime, which produces the later hardening and modifies the early setting of the other constituents, was decidedly decreased in amounts.

The effect of the higher magnesia, when not exceeding 8 per cent., was not very noticeable in any of the physical properties. Higher amounts produced a quick initial set and an apparent slow final set. The strength both in tension and compression of neat and mortar specimens, and of concrete specimens in compression, when 8 per cent. was not exceeded, was very comparable with the strengths produced by cements of normal magnesia content. Above these amounts the early strengths were less, but showed a consistent gain with age.

Specimens are still available for examination and breaking at later periods than those reported in this paper.

THE EFFECT OF HEAT ON CELLULOID AND SIMILAR MATERIALS.

By H. N. Stokes and H. C. P. Weber.

[ABSTRACT.]

When thoroughly cleansed cotton is immersed in a mixture of sulphuric and nitric acids, more or less of the latter acid combines with the cotton (cellulose), the amount depending upon the strength of the acid and on how long it is allowed to act. The most highly nitrated product is gun-cotton, the less nitrated being commonly known as pyroxylin, soluble cotton, etc. Pyroxylin, when dissolved in a suitable liquid, forms collodion. Mixed with camphor or similar substances, it yields the product popularly known as "celluloid," though legally this word should be applied only to material manufactured by one American company. The term pyroxylin plastics is of wider applicability.

Gun-cotton would be worthless if it did not break down or decompose with explosive violence, and the question naturally arises. To what degree do the closely related pyroxylin plastics share this instability? It is well known that they are readily ignited and burn rapidly. Evidence as to their explosiveness is contradictory, and instances of supposed spontaneous ignition have been published from time to time. The work described in this paper was done in the attempt to settle some of the questions involved.

Weighed samples, wrapped in tissue paper, were kept at various temperatures and afterwards reweighed and examined. It was found that even at the boiling-point of water there was considerable loss in weight, and some of the samples swelled up and formed brittle, spongy masses, while the wrappings were partially charred. When other samples, unwrapped, were heated to 135° C.

(275° F.), many of them ignited or exploded in less than two hours. At the same time, considerable volumes of combustible and poisonous gases were given off.

Still other heating experiments showed that samples of celluloid were more liable to ignite or explode—in other words, were less stable—than parlor and safety matches, black gunpowder, and two grades of smokeless powder.

Thin strips of celluloid burned many times as rapidly as paper or strips of wood of the same width and thickness. Sticks of wood 13 millimetres (½ inch) square would not continue to burn when lighted, but celluloid sticks of the same size burned almost as rapidly as the thin strips.

Although the results of the experiments show that celluloid is a highly inflammable and even explosive substance, the Bureau of Standards disclaims any wish or intention to discourage the use of this material. It can only inform the public of the necessity for reasonable carefulness in using and handling it.

TESTS OF LARGE BRIDGE COLUMNS.[1]

By J. H. Griffith and J. G. Bragg.

[ABSTRACT.]

THE investigation gives a comparative analysis of the experimental data found upon 18 large bridge columns when they were tested in the 10,000,000-pound testing machine. The action of each column as a whole was studied in a range of loadings taken to destruction of the members. Numerous observations were made to determine the behavior of lattice bars, pin plates, diaphragms, etc. The causes and effects of initial strain from riveting and fabrication were discussed.

GAS MANTLE LIGHTING CONDITIONS IN TEN LARGE CITIES IN THE UNITED STATES.[2]

By R. S. McBride and C. E. Reinicker.

[ABSTRACT.]

FROM a careful inspection of about 4500 gas mantle lamps in service in ten cities a summary of the condition of mantles, glassware, pilot light, and other particulars was made in order

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[1] Technologic Paper No. 101.

[2] Technologic Paper No. 99.

to determine to what extent the customer benefited through periodic maintenance service.

By these observations it is found that a lamp not on regular maintenance is likely to be defective 5½ times as frequently as a lamp which is regularly maintained. Also, it is shown that, on the average, one in three of the lamps on regular maintenance was not in good condition, whereas the defects noticed in the lamps not so maintained average more than one for every lamp.

The principal defects in maintenance systems were also investigated, and one satisfactory system of estimating the expenses for maintenance work, together with a set of unit costs, is presented, based upon the analysis of the operation of ten gas companies. A suggested table of costs for each type of unit is given.

PAINT AND VARNISH.[3]

[ABSTRACT.]

THIS publication is intended to give, without unnecessary detail, information which should be of value to those interested in the use of paint and varnish. After a general discussion and classification of paints and varnishes and an explanation of the process of "drying," the raw materials, including oils, driers, thinners, resins, and pigments that enter into the composition of paint or varnish, are individually described. The methods of manufacture and of testing varnishes are presented, ready-mixed or prepared paints are discussed, and somewhat detailed instructions on mixing paints and stains, on color blending, and on the application of paint and varnish to various surfaces are given. Specifications in common use for many of the materials treated and a glossary of painters' terms also appear.

RULES AND REGULATIONS PROMULGATED UNDER AUTHORITY OF THE FEDERAL STANDARD BARREL LAW.[4]

[ABSTRACT.]

SECTION 3 of the Federal Standard Barrel Law (38 Stat., ch. 158, p. 1186: 63d Cong.) reads in part as follows:

"SEC. 3. That reasonable variations shall be permitted and tolerances shall be established by rules and regulations made by the Director of the Bureau of Standards and approved by the Secretary of Commerce. . . ."

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[3] Circular No. 69.

[4] Circular No. 71.

This circular contains the rules and regulations which are authorized by quoted part of the above law. The text of the law is included as an appendix to the publication.

MATERIALS FOR THE HOUSEHOLD.[5]

[ABSTRACT.]

DESCRIBES the more common materials used by the household, comprising paint materials, cement, clay products, lime, plasters, and stucco, wood, metals, bituminous roofing, inks and dyes, adhesives, paper, textiles, rubber, leather, cleansers and preservatives, fuels, illuminants, lubricants and a concluding chapter on quantity in the purchasing of materials. Each title is treated under the general heads of composition and definition, sources, properties, uses, tests, preservation, hints as to selection and use, and references.

COMBINED TABLE OF SIZES IN THE PRINCIPAL WIRE GAUGES.[6]

[ABSTRACT.]

A TABLE combining in one series the sizes in the American (B. and S.), Steel, Birmingham (Stubbs's), British Standard, and Metric Wire Gauges, arranged in order of diameters of wires. It gives the diameters of all the gauge numbers in these five systems in mils, inches, and millimetres, also the cross-sections in square mils, circular mils, square inches, and square millimetres. The table is specially useful to manufacturers who wish to determine the nearest equivalent in American or British gauge sizes of wires specified in millimetres or square millimetres, or *vice versa.*

THE DETERMINATION OF ABSOLUTE VISCOSITY BY SHORT-TUBE VISCOSIMETERS.[7]

By Winslow H. Herschel.

[ABSTRACT.]

THE Engler and the Saybolt Universal viscosimeters, which are the instruments usually employed in the oil trade, have such short outlet tubes that the equation for the flow through long capillary tubes is not applicable without correction factors. The literature has been carefully reviewed and further experimental work has been done. The conclusion is reached that water is not a suitable liquid for use in finding the relation between viscosity and time of discharge for short-tube viscosimeters, and that Ubbelohde's equation, and all others based upon it, are seriously in error.

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[5] Circular No. 68.

[6] Circular No. 67.

[7] Technologic Paper No. 100.

Speed Control and Stopping Devices. ANON. (Safety Standards of the Industrial Board, Pennsylvania Department of Labor and Industry, Electric Code, vol. 1, No. 21, p. 59.)—The importance of automatic speed-limiting devices for certain types of prime movers is becoming better realized. More cases of rotating parts failing by overspeed occur than of boiler explosions, which are so seriously regarded. With steam turbines and belted water turbines such limiting devices are particularly needed. Even reciprocating engines are frequently fitted with extra valves and independent speed-limiting mechanisms. Water turbines in many cases have deflecting nozzles or vanes, usually operated by the governor, which serve to prevent overspeed. Generators driven by prime movers carry a load which may become nearly zero by the opening of automatic cut-outs. The speed-limit device may therefore need to be very quick acting, and yet, in cutting off the steam or water supply from the engine or turbine, must not cause any damage to the feeder piping.

Separately excited, direct-current motors are particularly liable to "run away," since their field excitation current may be greatly reduced, while the armature current still is maintained. To a less degree series motors, motor generators operating in parallel, or feeding storage batteries, and rotary converters are also subject to "runaways." Where directly connected to mechanical load, dangerous overspeed is not likely to occur, but where belt connected or having only a generator load, which may be readily lost by the opening or automatic cut-outs, the danger of overspeeding is considerable. Centrifugal devices which at high speeds actuate trip devices for opening the source of energy supply are most often utilized as means of protection against such a contingency.

With direct-current motors having speed adjustment through field control, dangerously weak fields must be avoided, since excessive speed may result from this cause, especially when the load is belt connected to the motor or consists of generators. Release coils, whether placed on starting rheostats or otherwise, in which the field circuit passes through the coil, are among useful means for preventing the dangerous weakening of fields during operation. In some cases centrifugal speed-limiting devices are installed.

Provision of more than one manual control device is often desirable for stopping prime movers or motors, since in emergencies this may save valuable time, especially where the equipment is of considerable extent and much distance might have to be traversed in order to reach a single point of control. Through the use of relay control circuits a single valve or main switch can readily be operated from several points.

The relative importance of electrical circuits controlling stopping devices, together with the natural frailty of the comparatively small conductors employed, makes the use of conduit or other mechanical protection essential to assure reliability.

The use of closed circuits assures that any chance open circuit will immediately give evidence of its existence through lamps or bells connected in the circuit. With open circuits a break in the circuit may not be discovered until in an emergency the control may be found inoperative. Where, as with motor-operated switches or valves, the control circuits must be normally open, it will be necessary to depend on the mechanical protection of the circuit for its maintenance in operative condition.

Coke from Peat. ANON. (*La Chronique Industrielle,* vol. 40, No. 295, p. 7, June 20, 1917.)—The Peat, Coal, and Oil Syndicate of Doncaster, Yorkshire, is developing a new method for treating a special variety of dry black peat and converting it into a hard foundry coke, the by-products being tar and tarry liquids from which automobile oils can be obtained by distillation. It is not claimed that all varieties of peat can be profitably used, but it is said that hundreds of acres containing millions of tons of peat can be commercially utilized by this process.

The black layer at the bottom of the bog is most suitable for the manufacture of coke. This material is freed of its excess of water and subjected to a carbonizing process by means of which by-products are recovered, the residue being a soft and friable coke. Notwithstanding that peat coke has lower sulphur content than any other combustible, up to this time its insufficient hardness has been an obstacle to its application in blast-furnace operation. This fault, it is claimed, is now overcome, and a hard, strong, and pure coke is now obtained. A German chemist has proved by analysis that 1000 tons of air-dried peat will produce 400 tons of coke, 40 tons of tar, and 400 tons of tarry liquids. The tar can be further distilled to yield 18 tons of crude oil, two tons of creosote, two tons of pitch, and eight tons of paraffin. The tarry liquids will yield four tons of sulphate of ammonium, six tons of acetate of lime, and two tons methyl alcohol. It is estimated that there will be a profit of 90 c. (centimes?) on every ton of peat so treated.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

THE PRODUCTION OF SEPIA TONES BY DIRECT DEVELOPMENT.[1]

By Adolph Nietz and Kenneth Huse.

[ABSTRACT.]

It is well known that slow developing-out photographic papers will give warm tones if overexposed and developed with a strongly restrained developer. Observations recorded in this paper were made in order to find the best conditions for producing sepia tones by this method.

The process is attended by uncertainties and is not by any means easy, but with great care in manipulation excellent sepia prints can be obtained with some subjects. The tone depends only upon the time of development, and with this time fixed good reproduction of tone can be secured, the exposure then being adjusted to get the necessary depth of print. For obtaining good sepia tones corresponding to the sepia water-color manufactured by Winsor & Newton, and free from the objectionable smokiness in the shadows, this process is particularly suitable. Since in development the print starts as a red-brown and passes through brown, sepia-olive, sepia, and olive, any of these tones can be obtained under given conditions.

Artura chloride is the only paper with which the writers could obtain satisfactory results, and it is to be understood that all subsequent statements imply the use of this material.

The most satisfactory developing agent was found to be chlorhydroquinone. Elon, hydroquinone, and other substituted hydroquinones were investigated, but chlorhydroquinone has the necessary properties for use as a restrained developer—proper sensitiveness to restraining agents, freedom from fog and staining, and stability.

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* Communicated by the Director.

[1] Communication No. 53 from the Research Laboratory of the Eastman Kodak Company, published in *British Journal of Photography* and *American Photography*.

The best working formula was found to be

Chlorhydroquinone	5 gm.
Sodium sulphite	30 gm.
Sodium carbonate	16 gm.
Potassium bromide	6 gm.
Potassium metabisulphite	6 gm.
Water	to 1000 c.c.

With this as a basis, a systematic series of experiments on the effect of each constituent was carried out. The principal fact brought out was the necessity of securing a proper balance between the concentration of potassium bromide and that of the potassium metabisulphite.

That the tone is dependent only on the time of development was indicated by the manner in which the print changed continuously in color while in the developer, as already stated. Any of the colors can be obtained by stopping development at the proper time. As the prints change color in the fixing bath and again on drying, judgment of tone should be based entirely on the appearance of the finished print. By developing test-strips for different known lengths of time, the correct time of development for any desired tone is determined.

The exposure being excessive (about 75 to 100 times normal), the use of nitrogen-filled tungsten lamps or other powerful light sources is recommended. When correctly exposed, the image is slightly printed out.

Since the process tends to shorten the scale of the paper by increasing the contrast, the range of negatives suitable is more limited than for ordinary reproduction. With soft portrait negatives of a certain type, good prints may be obtained using such tones as olive-sepia or decided olive, but another class of work for which this process is perhaps best adapted is the reproduction of paintings and etchings. A rich etching-sepia is readily secured in the latter case.

The image is not due to any oxidation product, but consists of silver, and the color depends on the state of division. For this reason prints made by this method are permanent.

Specific directions for working the process are given in the full paper to which reference has been made.

NOTES FROM THE RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY.*

THE SHAPES OF GROUP MOLECULES FORMING THE SURFACES OF LIQUIDS.[1]

By Irving Langmuir.

THIS paper outlines the author's theory of the shapes of group molecules, particularly of organic compounds, and gives the principles and results of his measurements of cross-sections and lengths of molecules.

In accordance with the theory of adsorption and surface tension earlier stated,[2] as well as considerable experimental evidence, adsorbed films on plane surfaces of solids or liquids should be, in general, one atom or group molecule thick.

When an oil is placed upon water the COO groups combine by their secondary valences with the surface of the water, while the hydrocarbon chains remain combined with each other. Spreading continues until all available COO groups have come in contact with the water, and then ceases. The hydrocarbon chains then extend above the water away from the COO groups on the surface, and their dimensions may be measured from the weight of oil, area which it covers, density, and molecular weight. The values for fifteen different organic compounds are given. The cross-sections vary from 21×10^{-16} sq. cm. to 280×10^{-16} sq. cm., and the lengths from 5.7×10^{-8} to 44.0×10^{-8} cm.

The bearing of the data upon the position of various radicals is discussed.

The theory is supported both by Gibbs's method of calculating the material adsorbed in the surface of a liquid from the change of surface tension, and still more conclusively by Szyszkowski's measurement of surface tension for certain organic acids, which last indicate that in each case the same number of molecules are adsorbed in the surface layer.

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* Communicated by the Director.

[1] *Proceedings of the National Academy of Sciences*, 3, 251–257 (1917).

[2] Langmuir, *J. Amer. Chem. Soc.*, 38, 2221–2295 (1916).

The article is already so condensed that anything in the form of an abstract omits material of significance. A more extended treatment will probably be soon published in the *Journal of the American Chemical Society.*

TUNGSTEN ELECTRODE LOSS IN THE HYDROGEN ARC.[3]

By G. M. J. Mackay and C. V. Ferguson.

A 2-MM. arc was run for 1.265 minutes in a 12-cm. spherical bulb containing 300 mm. pressure of hydrogen. The characteristics were:

Initial	201 volts, 1.40 ampères
Final	245 volts, 1.40 ampères

The temperature of the faces of the electrodes was 3112° K. for the cathode and 3151° K. for the anode. The cathode gained 75 per cent. of the loss in weight of the anode, and the rate of loss of the latter was not appreciably greater than would occur from the normal evaporation of the metal due to its temperature alone. The metal leaving the anode becomes positively charged and migrates to the cathode. The number of atoms carried for each unit charge is about 10^{-4}.

THE CRYSTAL STRUCTURE OF ALUMINUM AND SILICON.[4]

By Albert W. Hull.

THE crystal structure of aluminum and silicon has been determined by passing a narrow beam of monochromatic X-rays from a Coolidge tube with molybdenum target through a continuously rotated tube of the finely powdered metal and photographing the diffraction images of the slit. The positions and intensities of the lines in the photograph are compared with the theoretical values for different possible arrangements of atoms until an arrangement is found which represents completely the observed lines.

A tabulation of the lines observed and the corresponding spacing, calculated from the angle of the line and the wave-length, the theoretical spacing of the assumed lattice, and the index of the plane producing each line, is given.

Aluminum, which has usually been considered to belong to the isometric system, is shown to be tetragonal. The unit of structure is a centred rectangular prism, with a square base of 2.85 A., side and height 4.05 A., with an atom at each corner and one in the centre of the prism. The atoms per unit parallelopiped are 2.

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[3] *Physical Review,* 9, 573, 574 (1917).

[4] *Ibid.,* 9, 564–566 (1917).

Silicon has a lattice identical with that of the diamond, two face-centred lattices intermeshed, the one being displaced with reference to the other along a cube diagonal a distance of one-fourth the length of the diagonal. The side of the cube is 5.43 A., compared with 3.56 A. for diamond, and the distance between nearest adjacent atoms is 2.35 A., compared with 1.54 A. for diamond. The number of atoms per unit cube is 8.

THE EFFECT OF X-RAYS ON THE LENGTH OF LIFE OF TRIBOLIUM CONFUSUM.[5]

By Wheeler P. Davey.

THE action of X-rays upon the flour weevil (*Tribolium confusum*) has been studied with extreme accuracy of measurement, and control of other factors which might impair the accuracy of the observations. Probability curves have been plotted from the data in order to determine the idiosyncrasy of the organism.

X-rays above a certain threshold dose cause premature death after a latent interval whose duration is given by $Y = A - B \log X$ where Y is the length of the latent interval and X is the X-ray dose in terms of electrical input of tube, anti-cathode material, etc. The dose was varied by length of exposure, voltage current and distance being held constant.

The threshold dose with a standard Coolidge tube operating on sine-wave voltage without filters is 500 milliampère-minutes at 25 cm. distance at 50 kilovolts.

The influence of wave-length and of sterilizing effect of doses below the lethal dose is being studied.

THE CRYSTAL STRUCTURE OF IRON.[6]

By A. W. Hull.

THE analysis was made first on a single crystal, 6 mm. square and 2 mm. thick, of steel containing about 3.5 per cent. of Si and practically no carbon, and then on pure iron powder. The K lines appeared very clearly at 110,000 volts, and their distance from the centre of the beam could be measured. Comparison with an assumed structure of atoms arranged in a centred cubic lattice, with the scattering electrons in each atom concentrated at its centre, failed to account for all the lines. Displacement of all the electrons from the centre along the cube diagonals in four groups of 2, 8, 8, 8, at distances $^1/_{32}$, $^1/_{16}$, $^1/_8$, and $^1/_4$ respectively of the distance to the nearest atom, makes it possible to account for all the observed facts within the limit of the experimental error.

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[5] *Physical Review*, 9, 557, 558 (1917).

[6] *Ibid.*, 9, 84–87 (1917).

Although but a rough approximation, the excellent agreement indicates that this is a step in the right direction. Iron is given its correct valence thereby.

THE EFFECT OF X-RAYS ON THE LENGTH OF LIFE OF TRIBOLIUM CONFUSUM.[7]

By Wheeler P. Davey.

THIS is a detailed account of the work briefly described in the *Physical Review,* 9, 557, 558 (1917). A short review of the literature of the effects of X-rays on various forms of animal life is given.

The characteristics of *Tribolium confusum,* and the methods of manipulation employed to eliminate sources of error and the individual idiosyncrasy of the beetles are described in full.

A dose of 15,000 $\frac{\text{M.A.M.}}{25^2}$ at 50 kilovolts killed all beetles during administration. Doses less than 500 $\frac{\text{M.A.M.}}{25^2}$ at 50 kilovolts were not fatal to all the beetles.

THE PLIOTRON OSCILLATOR FOR THE PRODUCTION OF LARGE CURRENTS OR HIGH POTENTIAL AT HIGH FREQUENCIES.[8]

By William C. White.

THE use of a pliotron of the same type of design as that recently described[9] as a sort of converter to supply alternating-current energy from a direct-current source is described.

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[7] *General Electric Review,* 20, 174–182 (1917).

[8] *Ibid.,* 20, 635–637 (1917).

[9] *Ibid.,* 19, 771 (1917)

The principles and connections of arrangements of pliotrons for (1) the production of relatively large current and (2) for the production of relatively high voltage, both involving amounts of energy of the order of 150 volts or less, are given.

A diagram is shown (1) to produce currents of from 10 to 25 ampères from one tube at frequencies between 100,000 and 1,000,000 cycles, for such uses as calibrating a hot-wire ammeter by direct comparison with a standard.

The nearly reverse conditions for (2) are also described and shown. Both arrangements can be operated from a direct-current source betwen 200 and 750 volts, and at 100,000 cycles a voltage of 120,000 may be obtained from one pliotron tube operating from a 500-volt, direct-current source. For higher voltages tubes may be operated in parallel.

RÖNTGEN RAYS FROM SOURCES OTHER THAN THE FOCAL SPOT IN TUBES OF THE PURE ELECTRON DISCHARGE TYPE.[10]

By W. D. Coolidge and C. N. Moore.

THIS paper is a detailed study by means of the pinhole camera of the amount and distribution in the Coolidge X-ray tube of radiations that might tend to blur the röntgenogram. Illustrations show the relative intensity of the X-rays given off from different parts of the target, the effect of size of bulb and of increase of voltage, and the efficacy of various hooding and other devices for intercepting such radiations. Test pictures made under comparable conditions, with and without the use of such devices, are given.

The conclusion reached is that with the present technique it is not possible for even skilled röntgenologists to distinguish between the pictures taken without and those taken with such shielding devices. While the presence of X-rays emanating from other parts than the focal spot can be demonstrated, it is not of practical significance at this time.

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[10] *General Electric Review*, 20. 272–281 (1917).

Water Powers Conserve Labor. H. L. COOPER. (*Electrical World*, vol. 69, No. 25, p. 1200, June 23, 1917.)—Secretary Lane has recently stated that there is in the United States 35,000,000 water horsepower undeveloped. The attacks on water-power engineers and developers began in 1903, and since that time the aggregate falling off in water-power development amounts to more than 5,000,000 horsepower. In other words, if water-power development had been encouraged during this period and continued at the normal rate of development prior to 1903, we should have an additional 5,000,000 horsepower at work to-day, and the public would be fixing the rates to be paid for this great additional amount of energy. The consumers would be enjoying a saving of at least $50,000,000 annually in their power bills, and 100,000 laborers now engaged in following coal from the vein to the ash pile would be free for other more important work. Moreover, the development of this 5,000,000 horsepower would have been of great benefit to our farmers, because of the cheap fertilizer it would have produced. Besides this, about $274,000,000 worth of railroad equipment now hauling equivalent coal would be available for other most important needs.

Power in all its forms in the United States has been steadily going downward in cost for many years, yet in spite of this the average selling price of hydro-electric power is about $10 per horsepower less than the price of the same unit by steam. The crops in France, in England, in Germany, and in the United States are all suffering to-day from want of fertilizers. Volumes have been written showing that fertilizers, intelligently used, would about double the present farm production of the United States. The primary basic need of fertilizers is nitrogen; and this can be most economically produced by the arc process from the air. Ours is the only large country in the world where fertilizers by this process are not in successful use.

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BOOK NOTICES.

THE ANILINE COLOR, DYESTUFF AND CHEMICAL CONDITIONS from August 1, 1914, to April 1, 1917. Compiled by I. F. Stone. New York, The National Aniline and Chemical Company, 1917. 224 pages, 8vo.

In the great events of life, the attention of mankind is often focussed on incidents that are really minor in their significance, but which are either at once typical and easily understood, or by some combination of circumstances brought at once into the spotlight, and the first impression is never wholly lost.

The general war that broke out in the summer of 1914 produced almost immediately intense reactions in the industrial and commercial operations of the United States, and, so far as general public discussion was concerned, perhaps no more intense interest was awakened than in the coal-tar color manufacture. Yet the total value of synthetic colors imported into the United States in a normal year is only about nine millions of dollars, and one firm of chain stores in this country sells ten million dollars' worth of candy alone, and one automobile factory sells over one hundred million dollars' worth of its products in the same period.

The book before us is a very valuable contribution to the problem of establishing the tar industries in this country upon a basis which will prevent their being upset by competition from any other country. That these industries would be so established seems to be undeniable. It is not for colors alone. These have formed the subject of the most active discussion since the breaking out of the war, but, as noted above, the total consumption in this country does not present figures comparable with many other industries. It is the utilization of coal-tar (and incidentally, some other tars) for the manufacture of a variety of substances necessary in both peace and war. The modern high explosives belong to this class, and a country which is equipped to make the colors is equipped to make most of the other tar products. No great nation can afford to leave these manufactures in the hands of another great nation that may become suddenly hostile. It can scarcely be doubted that when the nations lay down their arms an economic war, fought with tariffs, trade agreements, combinations, and other methods to control competition, will break out, and those who desire to know the facts of the case will need to read this work carefully, and also a work recently published, "The British Coal-Tar Industry: Its Origin, Development, and Decline."

The National Aniline and Chemical Company, publisher of the work under consideration, is a combination of several of the most prominent and best-equipped establishments engaged in the manufacture of tar products. Its organization is a step in the right direction, for the complex procedures of manufacture and the intricate problems of marketing can best be solved by a company which can afford to employ a large staff of experts in both scientific and business departments.

Henry Leffmann.

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Allen's Commercial Organic Analysis: A Treatise on the Properties, Modes of Assaying, and Proximate Analytical Examination of the Various Organic Chemicals and Products Employed in the Arts, Manufactures, Medicine, etc. Fourth edition, vol. 9, edited by W. A. Davis, B.Sc., A.C.G.I. 836 pages, illustrations, 8vo. Philadelphia, P. Blakiston's Son & Co., 1917. Price, $5.

Directions for Designing, Making, and Operating High-pressure Transformers, by F. E. Austin. Second edition. 46 pages, illustrations, 12mo. Hanover, N. H., Author, 1917. Price, 65 cents.

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ERRATUM.

MAINTAINING PHOTOGRAPHIC STANDARDS, By Alfred B. Hitchins, Ph.D., August, 1917, issue of the JOURNAL, vol. 184, p. 179.

The formula page 194 should read:

$$\gamma\infty = \frac{\gamma 1^2}{2\gamma 1 - \gamma 2} = \frac{\cdot 82^2}{2(\cdot 82) - 1\cdot 36} = \frac{6724}{2800} = 2\cdot 40$$

CURRENT TOPICS.

Errors of Registration of Electricity Meters with Varying Loads. G. W. Stubbings. (*The Electrical Review* (London), vol. 81, No. 2067, July 6, 1917.)—The errors of registration of electricity meters over periods during which there is a variation of the current passing are a matter of considerable interest. The problem of obtaining the errors of meters on constant loads is one of great simplicity, but this information gives no *prima facie* indication as to the degree of accuracy with which a meter will register over a period during which the load may vary between wide limits. An interesting case of this question is that of a house in which a moderate load is used for a few hours in the evening, one light through the night, and an occasional use of one light, an electric iron, or some similar device throughout the day. The inaccuracy of the meter on one light may be considerable, but the important point is the extent to which this error will affect the total inaccuracy over such an extended period as one day. The present article is an attempt to investigate this question theoretically, and it may be observed that the results apply equally to cases of rapidly varying loads, such as are taken by certain machines. The investigation is concerned with ampère-hour meters only, and variations of voltage have not, therefore, to be taken into account. The performance of a theoretically accurate meter with varying currents has been previously investigated, and it is now well known that such a meter with eddy-current braking, whether shunted or not, correctly records the total quantity of electricity, notwithstanding any variation of the current.

The case of a meter of the commutator type may first be considered. With such a meter the error is due to an approximately constant frictional torque, and the percentage error curve is of the form $\eta = K - \frac{n}{c}$, η being the percentage error, n a constant depending on the frictional torque, K the percentage difference between the correct and ideal speeds of the meter, and c the current passing. Since the meter is inaccurate, the speed of the meter motor will correspond to an inaccurate value of the current, which will be

$$C_m = C\left(1 + \frac{K}{100} - \frac{n}{100\,C}\right)$$
$$= C + K\frac{C}{100} - \frac{n}{100}$$

This expression refers to instantaneous values of the current, which may be any function of the time. The quantity recorded by the meter will therefore be obtained by integrating the expression between the limits 0 and t', t' being the time during which current has been passing.

$$\int_0^{t'} C_m dt = Q + K \frac{Q}{100} - \frac{nt'}{100}$$

Q being the correct quantity. The percentage error will accordingly be $K-\frac{n}{C_a{}^1}$, C_a being the average current over the period t'. It therefore follows that in the case of a meter with an error curve of the form given the error of registration over a period will be the error at the average current over the same period, whatever be the nature of the variation of the current.

The case of a meter having fluid as well as solid friction may now be considered. With such a meter the error curve will be of the form $\eta = K - \frac{n}{C} - mC$, m being a constant depending upon the magnitude of uncompensated fluid friction. We have therefore:

$$C_m = C + K\frac{C}{100} - \frac{n}{100} - m\frac{C^2}{100}$$

$$\int_0^{t} C_m dt = Q + K\frac{Q}{100} - \frac{nt'}{100} - \frac{m}{100}\int_0^{t'} C\,dt$$

the percentage error being

$$K - \frac{n}{C_a} - \frac{m}{Q}\int_0^{t'} C^2 dt$$

The portion of the error due to fluid friction is therefore proportional to the ratio of the mean square of the current to the average value of the same, and such value of the fluid friction error will thus always be higher than that at the average load. In the case of most house-service meters, not only is the compensation for fluid friction fairly complete, but the effect of such friction is at the usual loads very small; the value of K is also, owing to the different shape of the error curve, higher than in the case of a meter with solid friction only. It is therefore legitimate to assume that the accuracy of a house-service mercury meter over extended periods will be equal to that of a commutator meter under similar conditions, the circumstance of variation of current only being taken into account. The effect of fluid friction with meters of higher capacities will become more important with varying loads, the magnitude depending upon the nature of the variation. With a load corresponding to $C = C_a(1 + a \sin pt)$, the ratio of the mean square to the mean current will be $C_a\ (1 + \frac{1}{2}a^2)$, and the effect of fluid friction is sensibly increased.

Power Requirements for Electrochemical Industry. F. A. LIDBURY. (*Journal of the Western Society of Engineers*, vol. xxii, No. 5, May, 1917.)—The most important single electrochemical industry in point of power requirements, and also in point of value of product, is the aluminum industry. So far as can be ascertained, there is something like 130,000 kilowatts of capacity installed in this country at present for the purpose of making aluminum. Not all of it, however, is in operation, because of conditions, particularly at Niagara Falls. In addition to these there appear to be about 60,000 kilowatts either being installed at present or contemplated. This indicates that the requirements of the aluminum industry alone in this country lie between 100,000 and 200,000 kilowatts. It is not easy to place a definite and arbitrary limit on the rate of growth of that particular industry. The demands seem to be increasing every year, and those demands are not, to a very great extent, war demands, but the increased demand has also come about by the rapid extension of the general uses of aluminum, as, for instance, in the automobile. Its use in the automobile is not only direct, but indirect, and includes the manufacture of certain steels and of steels of a nature which enables small light parts to be used in places demanding great strength in the automobile where a few years ago carbon steel of much greater dimensions had to be used.

Next in point of size, is a group of compounds which cannot very easily be separated from one another—the ferro-alloys, including ferro-silicon, ferro-chromium, ferro-molybdenum, and so on. It is a little difficult to estimate the power requirements of this class. Probably about 100,000 kilowatts would come near the mark. Calcium carbide, with 30,000 kilowatts or more, ranks next. The calcium carbide industry is not growing to-day at the same rate as a few years ago; the use of the carbide for illumination is not so great. On the other hand, the use of acetylene for welding and similar applications is increasing and is to-day, from an engineering point of view, by far the most important use of calcium carbide. Artificial abrasives follow with some 20,000 to 30,000 kilowatts or more, representing the necessities of this country in the manufacture of fused aluminum and silicon carbide, which constitute the basis of all modern grinder work. Then we have the electrolytic alkali business, which gives us caustic soda or caustic potash and chlorine in the form of bleaching powder. Liquid chlorine, or other chlorine products. For these, 30,000 kilowatts would be a reasonable figure to take for the requirements of the country.

The manufacture of chlorates, which are used in the match industry, in textiles, for the manufacture of oxygen, and in certain chemical operations, may be charged with 10,000 kilowatts. Again, sodium, which, of course, is not much used in its original form, but from which is made sodium peroxide, used in the textile industries as a bleaching agent, and is still more important as a starting point in the manufacture of sodium cyanide, will consume perhaps

15,000 kilowatts. There are also a number of minor articles, such as phosphorus, carbon bisulphide, and other products of the electric furnace or of electrolytic processes, which might include 1000 or 2000 kilowatts each. If the really small processes were considered, there are numerous little units working all over the country on numerous minor branches of electrolytic work which may take anywhere from a few kilowatts up to a few hundred.

Performance of Uniflow Engine in Steel Mill. ANON. (*Electrical World*, vol. 70, No. 6, p. 248, August 11, 1917.)—After sixteen months' service a uniflow engine installed in the steel plant of the L. F. Shoemaker Company, at Pottstown, Pa., was tested by the engineers of the steel company and showed very high economy, especially at small loads. The uniflow type of reciprocating engine is especially designed to maintain a steady temperature gradient in the cylinder and to operate at low constant losses, and, by means of an unusually simple valve gear, over a considerable range of load.

The engine which was tested is an Ames-Stumpf uniflow engine having a 19-inch diameter cylinder with 24-inch stroke. The engine is direct-connected with a 200-kilowatt, 250-volt, direct-current Crocker-Wheeler generator, which furnishes energy for electric cranes, heavy punches, shears, and general motor loads, and, in addition, all energy for the entire lighting system. The load is extremely variable, there being frequent flash-load fluctuations from one-half load to 25 per cent. overload. The unit operates at 200 r. p. m. with a pressure at the throttle vale ranging from 135 pounds to 150 pounds, with practically uniform vacuum, and is rated at 320 indicated horsepower with 150 pounds pressure, cutting off at one-fifth of the stroke.

The test is especially striking because it was made on an engine which had been working for many months in a steel mill. The vacuum was not particularly good, only 26 inches, and the running conditions for efficiency none the best. Considering all the conditions, the results were highly satisfactory for a simple condensing engine working over a wide range of power. Particularly noteworthy is the exceptionally uniform efficiency obtained through a range varying from quarter load to one and a quarter times full load, the variation in efficiency between these limits being approximately 10 per cent. The average consumption of dry steam per indicated horsepower at full load was down to the very creditable figure of 15 pounds, particularly as this result was a little better than that obtained before a forced run of sixteen months, giving the equivalent of two and a half years' operation on an ordinary ten-hour-a-day basis. The results show plainly that the development of new ideas in engine construction may well lead to real advances, despite the common belief that the reciprocating engine has reached about its ultimate development.

A Ship with No Reciprocating Machinery. ANON. (*Scientific American*, vol. cxvii, No. 5, p. 91, August 4, 1917.)—Machinery, just like living things, is undergoing a constant process of evolution. Types arise, become dominant, and then tend to disappear before the advance of newer and better adapted types. Though during the progress of one of these cycles it is generally difficult to determine just what is occurring, we appear to be witnessing a most important one to-day in the gradual conquest of the once dominant reciprocating machine by the rotary type. Thus, the turbine is threatening to displace the engine; the centrifugal pump, the piston pump; the electric locomotive, with its rotary motors, the steam locomotive; and others, cases of the same kind can be cited.

In this connection a tank steamer, now under construction in one of the Delaware River shipyards, is of interest because it is believed to be the first ship to be built without reciprocating apparatus of any kind in its engine-room. Its power plant consists of a low- and a high-pressure turbine geared to a single propeller, a surface condenser with a centrifugal pump driven by a turbine, two centrifugal hotwell pumps also driven by a turbine, and a rotary oil pump for the turbines and gears driven from the main gears.

None of this machinery is novel in principle or application; it merely happens that this is the first time that rotary machinery has been used consistently throughout a ship, thus marking definitely an epoch in the history of shipbuilding.

Undoubtedly the most interesting feature of the machinery itself is the use of a hydraulic dynamometer to measure accurately the total power developed by the turbines. The two turbines are connected to the propeller shaft by two sets of Westinghouse reduction gears, which permit the 3600-r. p. m. turbines to drive the propeller at 70 r. p. m. The dynamometer is incorporated in the pinion frames of the first gear, and its principle is as follows: The pinions and gears run immersed in oil and act as pumps, causing a considerable flow of oil under high pressure to the reservoir. The frames carrying the pinions of the first gears, while normally bolted securely in place, can be released and are so arranged that they will actually float on the stream of oil flowing from the pinions. The pressure of this oil represents the total pressure on the teeth of the pinion plus the weight of the pinion and frame. Therefore, for the gauge pressure of the oil (corrected from the frame and pinion weight) and the revolutions per minute, can be obtained the power transmitted, the sum of the power of both gears giving the total power delivered to the propeller.

Whale Meat as a Solution of the High Cost of Living. ANON. (*Scientific American*, vol. cxvii, No. 5, p. 92, August 4, 1917.)—The Bureau of Fisheries, Department of Commerce, has for some time, in correspondence and in personal interviews, been advocating the use of the meat of whales, porpoises, dolphins, and other cetaceans for human food.

Whales and porpoises are mammals, like cattle and sheep, and their flesh is "meat" and not "fish." In texture and appearance it resembles beef, though the color is darker red, and the flavor is closer to that of meat than to any other. It is devoid of all fishy taste. It is likely that it will soon be obtainable fresh, corned, and canned, and it is recommended to those who have the opportunity to purchase it.

Whales are taken at several shore stations on the Pacific coast, where their blubber is rendered for oil and their bones and flesh used to some extent for fertilizer, while their skins appear to be adapted to tanning into leather. These stations take a considerable number of these animals, each furnishing about five tons of excellent meat.

Porpoises are abundant on all our coasts, and there is a regular fishery for them at Cape Hatteras, where they are valued principally for their oil and to some extent for their hides.

During May an enterprising whaling company placed fresh whale meat on the market in Seattle, Wash., and Portland, Ore. The product met with a ready sale at 10 cents a pound, and was immediately placed on the menus of the hotels and restaurants under its proper name.

Extracting Alcohol from Garbage. ANON. (*Engineering News-Record*, vol. 78, No. 11, p. 534, June 14, 1917.)—Conserving the food supply of the country by turning city garbage into alcohol instead of using grain or potatoes for the purpose is a promising possibility established by carefully conducted experiments reported from the garbage-reduction plant of Columbus, Ohio. The experiments show that one ton of Columbus green garbage will yield 4.8 gallons of 95 per cent. alcohol of satisfactory quality. Estimates indicate that a $36,000 plant would produce from the 20,000 tons of garbage treated annually at the reduction works a total of 96,000 gallons of alcohol, giving a profit of 42 cents per gallon at war-time prices, or 30.5 cents under normal conditions. A year's garbage, the tests indicate, would yield as much alcohol as could be produced from 33,600 bushels of shelled corn, 39,529 bushels of wheat, or 110,344 bushels of potatoes.

The process is covered by United States Patent No. 1,114,017, granted to Dr. J. J. Morgan, 29 East Madison street, Chicago, Ill. In essence the process consists in extracting grease from garbage by cooking with sulphuric acid and steam, thereby converting the starch and allied products to dextrose; separating the grease from the tank liquor; neutralizing the acid sufficiently to allow fermentation; fermenting the liquor with yeast, thereby converting the dextrose to alcohol, and then recovering the alcohol by distillation.

The cost and profit figures relate to alcohol production alone; that is, they do not take into account the costs of the finishing process for grease and tankage. The insufficient tests showed lower yields of each than in ordinary garbage-reduction operations; but it was thought that by careful manipulation the tankage loss could be reduced to a small amount, if not eliminated, and that the grease produced would not be reduced either in quality or quantity.

The Nernst Vapor Lamps. ANON. (*The Electrician*, vol. lxxix, No. 10, June 8, 1917.)—Prof. W. Nernst describes a vapor lamp in German patents Nos. 288,228 and 288,229 which is somewhat similar to Darrah's lamp and is a decided improvement from the point of view of efficiency. The Nernst lamp rests on the phenomena which are observed when an arc passes between carbon electrodes in an atmosphere of zinc chloride or zinc bromide. These phenomena are analogous to those observed in the vapor of mercury and other metals. If the pressure of the zinc chloride vapor is too low, the light is dull, but at higher pressures (*e.g.*, at atmospheric pressure) the arc is sharp and bright. The chlorides of aluminum and titanium behave similarly to zinc chloride, titanium chloride being especially suitable for the object in view. The efficiency of these chloride lamps is about the same as in the high-pressure mercury vapor lamps.

According to one patent, the lamp includes a spherical bulb which contains the two carbons. The upper electrode is controlled by a solenoid suitably protected from the effects of the vapor. The lower part of the spherical bulb ends in a short, closed tubular connection which contains the salt to be vaporized. The volatilization is effected by an external source of heat; for this purpose the series resistance to which the lamp is connected may be suitably used.

In a second patent Nernst describes a vapor lamp in which the main conducting medium is mercury vapor; a suitable salt is added to give a better color to the light. The principle of the lamp consists in adding a line spectrum to that of the mercury vapor; in this way a white light is produced. Mercury vapor, however, has the property of continually removing any foreign substances. It is therefore possible to introduce the coloring matter continuously, if such substances are used as fuse at the temperature of the mercury vapor lamp. The substances thus continuously volatilize with the mercury, subsequently condensing and flowing back into the circuit in order to repeat the cycle of operations. Small conical glass protectors fused into the vessel surround the carbon and prevent the condensed drops of mercury and salt from reaching the arc. An especially suitable salt mixture for these lamps is said to consist of 70 per cent. zinc chloride, 15 per cent. calcium chloride, 5 per cent. thallium chloride, 5 per cent. lithium chloride, and 5 per cent. cæsium chloride. A lamp of this kind without a series resistance gives a light of 3000 hefner candle-power on 120 volts; it takes 4 ampères, and therefore has an efficiency of 0.16 watt per hefner candle-power, which is a considerable improvement on other electric lamps.

Leeds & Northrup Optical Pyrometer. ANON. (*Power,* vol. 46, No. 5, p. 149, July 31, 1917.)—Measurements by radiation can be carried out at a distance, once the laws of connecting temperature of radiating body and intensity of radiation have been determined, and the radiation receiving and measuring part need not be heated to the temperature of the radiating body, nor even near that temperature. Pyrometers utilizing radiation are divided into two classes—those which measure as heat energy the total radiation falling upon the receiving part of the instrument, and those, known as optical pyrometers, which are based on the fact that the luminous radiation or light varies in a definite manner as the temperature of the hot body changes.

The greatest success has been attained by separating out one kind or wave-length of radiation, usually that which excites the sensation of red, and comparing the intensity of this one-color light with the intensity of the light of the same color emitted by a standard source of light. The eye is very sensitive when comparing the brightness of two surfaces when one is superposed upon the other, and, after having arranged to have light from the hot body and light from the standard of comparison viewed in this relation, they can be made equal, either by varying the amount of light received from the incandescent object or by varying the intensity of the standard of comparison.

The latter method—that is, variation of the standard of comparison—is used by the United States Bureau of Standards. The Leeds & Northrup Company, of Philadelphia, under the fundamental Morse patents, has lately developed this type of optical pyrometer. The instrument, which is essentially a monocular telescope, is suitable for measuring from dull red (about 1100° F.) up to the highest known temperature. Between the eyepiece and the objective a tungsten lamp filament is located in the plane containing the point to which rays from the hot body are brought to a focus. By means of the eyepiece, the observer views the incandescent filament, which appears to lie upon the image, just as the cross-hairs of a surveyor's telescope appear upon the distant object viewed. By means of a rheostat in a case slung about the neck, the case also containing a storage battery and milliammeter, the current through the lamp is adjusted until the brightness of the filament and that of the image are equal, and the temperature is determined by referring the milliammeter reading to a calibration curve. In observing bodies at such high temperatures as 2500° to 10,000° F., the light received would be too blinding for direct observation, even through the red glass with which the eyepiece is provided, and also beyond the capacity of the lamp. Therefore a screen is used, placed between the lens and the image so that it reduces the light from the hot body but not that of the filament. This screen can be thrown in or out of the field of view when required, the readings being referred to a different calibration when the screen is in use.

A New Permanent Magnet Steel. ANON. (*Scientific American,* vol. cxvii, No. 6, p. 107, August 11, 1917.)—A new steel of considerable importance has been made in the United States for the last year or so, directly the outcome of war conditions. It is a new permanent magnet steel, a substitute for the older steel; it is known as tungsten magnet steel, used exclusively for this purpose before the war. Not long after the war began and the price of tungsten advanced, efforts were made to find a steel that would be cheaper and also as efficient as the permanent magnet steel then being used, containing tungsten varying in amount from 5 to 10 per cent. and sometimes even up to 25 per cent. The demand was insistent from both magneto makers and electric companies making electric meters, because the tungsten magnet steel was reaching prohibitive prices. It was even stated that automobile makers were substituting batteries for magnetos because American steel makers could not make as good magnet steel as foreigners.

The new steel, which is reported to be not less than 90 per cent. as efficient as the old permanent magnet steel, is a 0.90 per cent. carbon steel containing about 2 per cent. of chromium, and is now being made in electric furnaces in this country and extensively used by many consumers. This new type of steel is based on investigations made by Dr. John A. Matthews, of Syracuse, N. Y., and published by the American Society for Testing Materials about three years ago, in which it was pointed out for the first time that certain types of steels are better magnetically when quenched in water. This statement was contrary to all previous ideas regarding the hardening of steel for permanent magnets.

Magnetically this new chromium steel is equal to tungsten magnet steel in permanence and somewhat lower in residual density. Users have found it possible to substitute this steel for the older steel without making any change whatever in their windings or in the cross-sections of the magnets used. Practically chrome magnet steel, as the new steel is called, is not equal to the tungsten magnet steel, because it requires oil hardening and also because chrome steel in its natural state is much harder to drill or machine and the steel itself must be handled with greater care and uniformity in heat treatment than is necessary with tungsten steel. A large electric manufacturing company has been using this material for permanent magnets. By close coöperation with the manufacturers of the steel and careful development of treatment processes they have been able to obtain entirely satisfactory results.

Voltage Standardization. M. D. COOPER. (*General Electric Review*, vol. xx, No. 7, p. 564, July, 1917.)—One of the fundamental factors of our present-day civilization is standardization. In fact, it may be said that our entire economic and commercial development has been brought about by standardization or coöperation in the use of standardized measures of quantity and value, standard methods of action, etc. The electrical industry of this country has grown to its present importance and high state of development very largely by reason of the high degree to which electrical apparatus, appliances, material, and methods have been standardized. Although the electrical industry is outranked by no other industry in thoroughness of standardization, yet there is one feature that shows a considerable lack of standardization; namely, voltage distribution. There is, of course, a standardization of ranges of voltage, such as 105 to 125, 220 to 250, etc., but in any one of these ranges there is no commonly accepted standardization upon certain definite values. If voltage standardization upon a very few values could be brought about, a very great benefit would accrue to the electrical industry.

Since the incandescent lamp requires the closest voltage selection of any piece of current-consuming apparatus, the conditions surrounding the manufacture of incandescent lamps have always had a very large part to play in the selection of operating voltages for lighting companies. At an early period of the industry, practically all central stations were operated at either 100, 104, or 110 volts. In time the desire for a wider distribution and more economical use of copper led the lighting companies to seek higher voltages than 110, with the result that ultimately the demand for lamps was spread over a range from 100 to 130 volts, although now the greater proportion of the demand lies between 110 and 125 volts. With the introduction of the tungsten filament lamp there has been a decreasing necessity for a wide range of operating voltages, because lamp manufacturers have continuously been able to make their lamps closer and closer to the predetermined voltage of design. At the present time the processes of manufacture are so far developed that Mazda lamps can be made true to voltage within commercial limits. As the influence of the manufacturers has been withdrawn from maintaining a diversity of demand for various voltages, the trade has shown an evident tendency toward standardization of certain voltages. The tendency now is toward a universal standardization on 110, 115, and 120 volts.

The Detinning Industry. ANON. (*Reactions,* Second Quarter, 1917, vol. 10, No. 2, p. 30.)—Before the outbreak of the war, the production of tin plate in England was 700,000 tons per year, while in the United States the yearly output was over 1,000,000 tons, and at present the production is estimated at 1,300,000 tons. As the industry grew to large proportions, the disposal of the clippings and other scrap, which accumulate in large quantities, became an important problem, because, unless the tin could be removed from the iron, the scrap could not be puddled, or remelted in melting furnaces. This at first did not appear to be very difficult, and it appealed to the inventor, as the can factories were glad to give away their tin scrap and even to pay cartage simply to be rid of it.

Promising as the problem appeared, it required many decades of study and experiment before a profitable method was developed.

All the processes which have been actually operated may be divided into three general classes: the mechanical process, the chemical process, and the electrochemical process. In the mechanical process the effort was made to separate the tin from the iron by means of heat, and later by refrigeration. The method was not practical, however, because it was not possible to obtain a thorough separation of the tin from the iron. Most of the chemical and electrochemical processes were also failures, because the acids used would not dissolve the tin sufficiently and left a considerable amount adhering to the iron. It was also found in many cases that the chemicals used were too expensive to make the process an economical one. Three processes, however, have operated successfully, more or less in competition with each other for the last forty years. These three processes are the electrolytic alkali process, the chlorine process, and the alkali chemical process. Despite its apparent simplicity, the electrolytic alkali process was supplanted by the early chlorine process

When dry chlorine is brought into contact with tin clippings, the chlorine and tin will combine, and the anhydrous tetrachloride of tin which is formed will drip off. As chlorine at low temperature does not attack iron, the process is apparently very simple. Notwithstanding its seeming simplicity, it required a number of years to develop the process in such a way that it could be used commercially. In 1907 the chlorine process gained real importance in the hands of the Goldschmidt Company, which abandoned the electrolytic method which it had developed in favor of the chlorine process. Since then it has grown very rapidly, and to-day there are larger quantities of tin scrap and old tin cans detinned with the chlorine process than by all the other processes combined.

Another process is detinning by means of alkalies, either alone or in combination with oxidizers. This method was practised at an early stage of the industry, but it did not always remove a sufficient amount of tin, with the result that a considerable part was left on the iron. It is only within recent years that this process, using alkali and saltpetre, has been satisfactorily developed, and the results compare in every respect with the product of the chlorine process. The Goldschmidt Detinning Company uses this process as well as the chlorine process in its various plants, and its output, in addition to detinned scrap, comprises large amounts of tetrachloride of tin and pig tin of a purity which in every respect is the equal of Straits tin. The company recovers every year the equivalent of almost 2000 gross tons of metallic tin.

Metallurgy of Ferrochromium. R. J. ANDERSON. (*Iron Trade Review*, vol. lxi, No. 1, p. 75, July 12, 1917.)—Ferrochromium, like ferrosilicon, was one of the pioneer alloys made in the electric furnace at the time when this appliance was first used for the manufacture of the ferro-products. The use of chromium in alloy steels has markedly increased, and its employment promises to further increase on account of the special properties it confers upon the metal. Chromium steels are well adapted for use in the manufacture of armor plate and for armor-piercing projectiles, as well as for automobile parts, and in other cases where great hardness and high tensile strength are desired. In combination with nickel, chromium forms the now well-known chrome-nickel steel of the trade. Recently it has been employed with tungsten for magnet purposes.

Prior to the introduction of the high-temperature electric-melting furnace, the manufacture of ferrochromium was performed almost entirely in the blast-furnace stack, although a smaller amount was made in the crucible. Crucible manufacture gives high-tenor alloys, but several concomitant disadvantages are present. Only small charges can be fired at a time, the crucible cost is high, as special and expensive pots are required, and the alloys, though rich in chromium, are also comparatively high in impurities. The product is therefore not always satisfactory. For commercial purposes the electric furnace affords a satisfactory appliance in which alloys high in chromium tenor and low in impurities can be smelted. The large quantities demanded in steel metallurgy for chromium steel production are now made in the electric furnace in the United States, Germany, and elsewhere. The modern ferrochromium is a high-percentage alloy containing 60 per cent. chromium or more, and the physical properties are directly a function of the amount of carbon present.

Only a small amount of ferrochromium is made in the blast furnace at the present writing, for the reason that the electric furnace is more efficient where the power cost is low, and, further, the electric furnace turns out a better product. When ferrochromium is made in the blast furnace it requires a heavy fuel consumption for its successful manufacture; about three tons of fuel per ton of 40 per cent. alloy are used. The modern method of making ferrochromium is in the electric furnace, although a lesser quantity is produced by the thermit method. Generally speaking, the iron-chromium alloy produced in the electric furnace analyzes about 60 to 65 per cent. chromium and 5 to 9 per cent. carbon.

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THE METALLURGY OF TITANIUM.*

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I. INTRODUCTION.

So far as has come to the attention of the writer, there has never been any systematic attempt to set forth a metallurgy of titanium, or, for that matter, to take cognizance of the fact that the element possesses an extremely interesting and somewhat complicated metallurgy. If volume of scattered literature is any criterion, the importance of titanium, long recognized as a rare element, has assumed such proportions that it would seem consistent and harmonious with modern ideas if the principal writings were collated. The service that titanium in the form of a ferro-alloy renders to the iron and steel industry is one that is becoming more indispensable as the demands for quality become more exacting. A large industry has been reared upon the exploitation and sale of such an alloy, and in another works it forms one of the principal products of the establishment. The success of Rossi after many years of endeavor is of an excellence so signal and so arresting that it is certain to reawaken the latent interest in

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other of the now rare elements; *e.g.*, boron, calcium, strontium, barium, magnesium, zirconium, and others.

In any presentation of this subject, one is confronted by a number of difficulties, so that no attempt has been made to set forth an exhaustive treatise. The subject naturally falls under these heads: mineralogy and geology of titanium; chemistry of titanium; titanium in iron and steel and in non-ferrous metallurgy; and the uses of titanium and its compounds. These items, while not treated *seriatim*, are discussed in the paragraphs herein. The work, of necessity, has called for somewhat of a compilation of the writings of various authors, so I hope to be excused from what might appear to be an indiscriminate plagiarism. This can scarcely be avoided under the circumstances.

Acknowledgments.—Mr. A. Thompson, general manager of The Titanium Alloy Manufacturing Company, Niagara Falls, N. Y., kindly provided me with a set of titanium-treated Bessemer and open-hearth steels, and corresponding non-treated steels for comparison. Mr. Geo. F. Comstock, metallographist for the same company, has accorded me permission to reproduce some of his photomicrographs. Dr. Thos. L. Watson, director of the Virginia Geological Survey, has allowed me permission to show some of his photographs, as have Mr. Van H. Manning, director of the United States Bureau of Mines, and Dr. Joseph T. Singewald, Jr., of Johns Hopkins University. I have also shown some illustrations with the permission of the Goldschmidt Thermit Company, New York City, and Mr. George B. Waterhouse, Lackawanna Steel Company, Buffalo, N. Y. These courtesies are fully acknowledged in the text.

2. THE CHEMISTRY OF TITANIUM.

History of the Element and General Statement.—The element titanium was discovered by the Rev. William McGregor, in 1791,[1] while studying a magnetic black sand occurring at Menachan, Cornwall. In 1794,[1] Klaproth, while engaged in an investigation of rutile, discovered a new metal, which he named titanium. McGregor had given the name of menaccanite to the magnetic black sand, and to the newly discovered element the name menachite. In an investigation of ilmenite some time later—1797, to be exact—Klaproth showed that titanium and menachite were one and the same element. At any rate, the name titanium has been universally adopted, and menachite is referred to only in historical considerations. Titanium is one of the 80-odd elements which either in combination or elemental make up the crust of the earth and the surrounding atmosphere. Relatively speaking, it is a common element, although long considered rare. Elemental titanium is unknown in nature, it being found most commonly in combination with oxygen, as titanium dioxide (TiO_2), in three minerals; viz., brookite, rutile, and anatase.

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[1] AUTHOR'S NOTE.—There is some difference of opinion as to the exact dates here; the first is given as 1789 and the second as 1795 in some writings.

Physical and Chemical Properties.—Titanium[2] is a member of that group of elements to which also belong silicon, zirconium, cerium, and thorium. It bears a most marked resemblance to these elements, particularly in its tetravalency, although it has a lower valence in some cases; and it is, further, as is zirconium, either a weak base-forming or a weak acid-forming element. In its behavior towards reagents, titanium resembles tantalum to a certain extent. Titanium is a silvery-white metal—its color being not unlike that of highly polished steel; its fracture is steely. From a metallurgical standpoint, one of its most interesting properties is its workability; when cold it is brittle, but at a red heat it may be readily drawn and forged. The atomic weight is 48.1, and the specific gravity is given as 4.50. All attempts to draw it into wire have met with defeat on account of its non-ductility, either hot or cold, but, as stated, it is malleable at a low red heat and may be readily forged like iron. Hunter[3] determined the melting-point as between 1800° C. and 1850° C., and other determinations have been variable. Moissan[4] states that the element combines with oxygen with incandescence at a temperature of 610° C. On heating, it combines with the halogens and oxygen with incandescence to form halogen and oxygen salts, and with sulphur and carbon to form sulphides and carbides. Titanium combines with nitrogen with very great avidity, resulting in the formation of nitrides, resembling in this respect both boron and magnesium; the reaction commences at or about 800° C., and when the combustion of the metal occurs in air or in the presence of oxygen the oxide as well as the nitride is formed. Titanium is soluble in cold, dilute sulphuric acid, aqua regia, and hot concentrated hydrochloric acid; it is attacked rather more slowly by nitric acid, and more slowly still by dilute hydrofluoric and acetic acid.

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[2] Roscoe and Schorlemmer, "Treatise on Chemistry," 1907, p. 787 *et seq.*
Browning, P. E., "Introduction to the Rarer Elements," 1909, p. 99 *et seq.*
Hunter, M. A., "Metallic Titanium," *Jour. Am. Chem. Soc.*, vol. xxxii, 1910, p. 330 *et seq.*

[3] Hunter, M A., *loc. cit.*

[4] Moissan, H., "Traite de chemie minerale," tome ii, p. 494.

Preparation of Metallic Titanium.—Whether pure metallic titanium had ever been prepared prior to the work of Hunter in 1900 is rather doubtful. The common methods which were employed, calling for a reduction of titanium dioxide (TiO_2) by heating with metallic sodium and magnesium, normally yielded contaminated products containing titanium monoxide in greater or less amount. The product yielded by the action of sodium on the halogen derivatives of titanium also contained small amounts of titanium monoxide, produced by the action of any moisture present; in the same method the nitride was often found in the product, due to the union of titanium and nitrogen. To exclude nitrogen in this method is exceedingly difficult and calls for delicate manipulation. The early investigators readily confounded the nitride with the element itself because of the confusing metallic appearance of the former; the compound formed by titanium with carbon and nitrogen (*i.e.,* titanium cyanonitride) was also thus confused.

Probably the nearest approach to the pure element, before the work of Hunter, was secured by Moissan. The French savant fused carbon with an excess of titanium dioxide in the electric furnace at exceedingly high temperature. From his procedure are secured three distinct products in as many different layers; viz., the top layer, consisting of titanium, with about 5 per cent. of carbon; the second layer, consisting of the nitride; and the third, or bottom, layer, consisting of titanium monoxide. If the top layer be again fused with an excess of titanium dioxide the carbon is reduced to 2 per cent. and the product is free from silicon and nitrogen.[5] Moissan employed, in his method, a magnesia or lime crucible for the fusion. The carbon in the product was no doubt in the form of the carbide, TiC (in the absence of high silicon this would be the normal occurrence), and in addition there was oxygen; the product was then almost anything but pure titanium. When prepared by the method just described, the product has a brilliant, white fracture and is extremely hard but is quite friable. Its specific gravity is higher than that of pure titanium, being 4.87. Moissan, in further work[6] on titanium, distilled the metal in the electric furnace; the distillate condensed in small crystals. The production of pure metallic titanium is difficult by reason of the high melting-point of the element, and this is augmented on account of its strong affinity for nitrogen, carbon, and oxygen. In addition to Moissan, other early workers who labored in the endeavor include Wollaston,[7] Rose,[8] Berzelius,[9] Wöhler,[10] and Deville,[11] as well as Nilson and Petersson.[12] The latter workers attempted the preparation of pure titanium by the reduction of titanium tetrachloride ($TiCl_4$) with sodium, by heating the materials to a red heat in an air-tight steel cylinder. The results were disappointing. Titanium, or rather the product secured by this process, is in the form of yellowish scales. The best product contained 94.73 per cent. titanium, and the chief impurity was oxygen. In the Goldschmidt and Rossi processes for the production of the pure metal, the reducing power of aluminum is taken advantage of. A modified Goldschmidt method[13] is employed, where a peroxide (usually barium or sodium peroxide) is introduced into the mixture to cause an accelerated rate of reaction and accordingly produce a higher temperature. Considerably more aluminum is needed, for the successful use of this method, than in the straight alumino-thermic method, to provide for combination with the oxygen of the peroxide.

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[5] Moissan, H., *Compt. Rend.,* 1895, vol. 120, p. 290.

Hunter[14] attempted to produce pure titanium by a number of processes, and among others repeated the work of Moissan and of Nilson and Petersson. Poor results were obtained by all the methods employed until he used the method of Nilson and Petersson and employed most rigorous care. He then succeeded in producing virtually pure titanium. Hunter used titanium tetrachloride formed by the chlorination of titanium carbide; the chloride was fluxed in a current of nitrogen in order to completely remove all traces of chlorine, and then distilled repeatedly with the rejection of the end fractions. That fraction boiling near 136° to 137° was then shaken repeatedly with sodium amalgam and mercury and redistilled, producing a water-like substance boiling at constant temperature. Five hundred grammes of the titanium chloride and 245 grammes of sodium (the amount required theoretically for the complete reduction of the titanium) were mixed and placed in a steel bomb. The bomb and the enclosed mixture were brought to a low red heat—the reaction taking place. On cooling, the contents were leached with water; the residue consisted of pure titanium, partly as a fine, gray powder and partly as small, rounded beads. The reaction taking place in the bomb is rapid, and the heat generated is enough to melt some of the metal—hence the appearance of part of the product as small beads. That the product is pure titanium is shown by two analyses of the small beads; viz., 99.90 per cent. and 100.20 per cent. titanium. The method just described is standard for the production of pure titanium.

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[6] Moissan, H., *Compt. Rend.*, 1906, vol. 142, p. 673.

[7] *Phil. Trans.*, 1823, vol. 17.

[8] *Pogg. Ann.*, 1825, vol. 4, p. 3.

[9] *Pogg. Ann.*, 1837, vol. 14, p. 57.

[10] *Compt. Rend.*, 1849, vol. 29, p. 505.

[11] *Compt. Rend.*, 1857, vol. 45, p. 480.

[12] *Zeit. physikal. Chem.*, 1887, vol. 1, p. 25.

[13] Kuhne, K. A., *Electrochem. and Met. Ind.*, 1909, vol. vii, p. 127.

[14] Hunter, M. A., "Metallic Titanium," *Jour. Am. Chem. Soc.*, 1910, vol. xxxii, p. 330 *et seq.*

Compounds of Titanium.—According to Browning,[15] the following are typical compounds of titanium; viz., oxides, TiO, Ti_3O_4, Ti_2O_3, Ti_7O_{12}, TiO_2, Ti_2O_5, TiO_3; hydroxides, $Ti(OH)_4$, $Ti(OH)_6$; chlorides, $TiCl_3$, $TiCl_4$; bromide, $TiBr_4$; iodide, TiI_4; fluoride, TiF_4; titanofluorides, R_2TiF_6, etc.; sulphides, Ti_2S_5, TiS_2; sulphates, $Ti_2(SO_4)_3$, $Ti(SO_4)_2$; nitrides, Ti_3N_4, Ti_5N_6, TiN_2; carbide, TiC; silicide, TiSi; titanates, $RTiO_3$, R_2TiO_3; acids (see hydroxides), H_2TiO_3.

Oxides.—Titanium combines with oxygen to form a number of oxides, the most important being titanium dioxide (TiO_2), titanium sesquioxide (Ti_2O_3), and titanium peroxide (TiO_3). In addition to these, the monoxide (TiO) has been prepared and others have been described. The existence of some of these latter is doubtful. Titanium dioxide is trimorphous, occurring as three different minerals; viz., rutile, brookite, and anatase, as already mentioned. Titanium dioxide fuses at the temperature of the oxyhydrogen flame, forming a thin liquid which solidifies to a confused crystalline mass. In point of stability no other known compound surpasses TiO_2. Its heat of formation has been determined by W. G. Mixter [16] to be about 218,000.

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[15] Browning, P. E., "Introduction to the Rarer Elements," 2nd ed., 1909, p. 99.

The compound of titanium most deserving of the attention of the metallurgist, because it is the most useful, is the carbide (TiC). In combination with iron, it is found in the commercial alloy known as "ferro-carbon titanium." When titanium carbide is heated to redness in oxygen or in the air, it reacts with vigor with oxygen in a manner not unlike pure metallic titanium. The interesting compound titanium cyanonitride may be mentioned in this connection. When iron ores containing titanium are reduced in the blast furnace, small, brilliant, copper-colored cubes are found in cavities of the slag and pig iron, and replacing mortar in the fire-brick lining. A mass containing 80 pounds was found in a blast furnace in the Harz. The crystals are hard enough to scratch glass, and are highly refractory. The compound was noted by Wollaston [17] in 1822; he, at the time, thought it to be pure titanium, like many of the other early investigators. In 1849, Wöhler showed that it contained both nitrogen and cyanogen and ascribed to it the formula $Ti(CN)_2, 3Ti_3N_2$. Its specific gravity is 5.28, and it is highly resistant to the attack of acids, being attacked only by a mixture of nitric and hydrofluoric acids.

3. THE GEOLOGY AND MINERALOGY OF TITANIUM.

Occurrence and Mineralogical Forms of Titanium.—Titanium is a constituent which is characteristic of certain pyrogenetic compounds. It is almost always found in igneous rocks and in the sediments derived therefrom. Clarke [18] states that out of 800 igneous rocks analyzed in the laboratory of the United States Geological Survey 784 contained titanium. The commonest occurrences of titanium are as ilmenite, rutile, titanite, and perofskite; and it is also often concentrated in beds of titanic iron ore. The element enters into the make-up of many minerals, but rather rarely in anything like considerable quantity in any given locality. It occurs in a variety of mineralogical forms, mainly as oxides, titanates, and silico-titanates; further, it enters into the composition of many silicates as well as certain tantalates and niobates. As the oxide—chiefly rutile—titanium occurs in some rock magmas comparatively poor in base formers but rich in silicon. Where there is sufficient calcium and titanium, calcium titanate (*i.e.*, perofskite) is formed. In magmas which are richest in iron and leanest in silicon, titanium combines with ferrous iron to form iron titanate; *i.e.*, ilmenite.[19] Titanium is quite frequently present in ferric oxide—hematite—in variable amount, and in iron ferrate; *i.e.*, magnetite. It is often found also in small amounts in biotite, augite, amphiboles, certain varieties of garnet, and in some other silicate minerals. Traces of it have been detected in trap and basalt. Its presence has been observed in mineral waters, in many clays, occasionally in certain coals, in meteorites, and in most fertile soils. It has been detected in the sun's atmosphere by means of the spectroscope. Small amounts of titanium have been found in certain varieties of woods, in the ashes of all plants, [20] and bone, [21] in cowpeas, and in cotton-seed meal. The titanium minerals given in Table I [22] have been recognized and described in the literature. Many of them are rare and of only academic interest.

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[16] Mixter, W. G., *Am. Jour. Sci.*, January, 1912, vol. iii (ser 4), pp. 45-48.

[17] *Phil. Trans.*, 1823, vol. 17.

[18] Clarke, F. W., "The Data of Geochemistry," Bull. 616, U. S. Geological Survey, p. 21.

Table I (after Watson and Taber).

*Titanium Minerals.**

Mineral	Composition	Contains TiO_2, per cent.
Oxides:		
Rutile †	TiO_2	100
Octahedrite (Anatase)	TiO_2	100
Brookite †	TiO_2	100
Titano-magnetite	Magnetite (Fe_3O_4) with variable TiO_2	Variable up to 25

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[19] Iddings, J. P., "Igneous Rocks," 1909, vol. i, pp. 60, 64, 145.

[20] Wait, *Jour. Am. Chem. Soc.*, 1896, vol. 18, p. 402.

[21] Baskerville, Chas., *Jour. Am. Chem. Soc.*, 1899, vol. 21, p. 1099.

[22] Watson, T. L., and Taber, S., Bull. No. 111-A, Virginia Geological Survey, pp 10, 11.

* Compiled from Dana, E. S., "A System of Mineralogy"; Hintze, C., "Handbuch der Mineralogie," and other sources.

† Varieties omitted.

TABLE I (*Continued*).

Mineral	Composition	Contains TiO_2, per cent.
Titanates:		
Ilmenite †	$FeTiO_3$	52.7
Pyrophanite	$MnTiO_3$	53.1
Geikielite	$MgTiO_3$	67.7
Perovskite	$CaTiO_3$	58.9
Pseudobrookite	$Fe_4(TiO_4)3$	42.9
Arizonite	$Fe_2O_3.3TiO_2$ or $Fe_2Ti_3O_9$	58.8
Knopite	$RO.TiO_2$. Closely related to perovskite, but contains cerium	64.1–58.7
Iserite	$FeTi_2O_5$	69.5
Titano-silicates:		
Titanite †	$CaTiSiO_5$	40.8
Schorlomite	$3CaO.(Fe,Ti)_2\ O_8.\ 3(Si,Ti)O_2$	12.5–22.1
Keilhauite	$15\ CaTiSiO_5.\ (Al,Fe,Y)_2(Si,Ti)O_5$	26.7–36.6
Guarinite	$CaTiSiO_5$	40.8
Tscheffkinite	Related to keilhauite but uncertain	16.1–21.2
Astrophyllite	$(Na,K)_4(Fe,Mn)_4Ti(SiO_4)_4$	7.1–13.6
Aenigmatite	$2Na_2O.\ 9FeO.AlFeO_3\ 12(Si,Ti)O_2$	5.6
Cossyrite	Similar to aenigmatite	Undetermined
Yttrotitanite	See keilhauite	See keilhauite
Lamprophyllite	Related to astrophyllite	Undetermined
Neptunite	$R_2RTiSi_4O_{12}$	18.1
Johnstrupite	A complex silicate of the cerium metals, Ca and Na chiefly, with Ti and F	7.6
Mosandrite	Very near Johnstrupite	5.3–9.9
Rinkite	Near Johnstrupite and mosandrite	13.4
Ivaarite	Similar to schorlomite	18.98
Carlosite	Same as neptunite	18.1
Benitoite	$BaTiSi_3O_9$	19.3
Lorenzonite	$Na_2(TiO_2)Si_2O_7$	35.2
Yttrocrasite	A hydrous titanate of the yttrium earths and thorium	49.7
Delorenzite	$2FeO.UO_2\ 2Y_2O_3.24TiO_2$ (?)	68.9
Davidite	TiO_2 with Fe, U, V, Cr, and rare earths.	50.0+
Narsarsukite	Acid titano-silicate of ferric iron and sodium	14.0
Niobates and Tantalates:		
Pyrochlore	$RNb_2O_6.R(Ti,Th)O_3.NaF$	5.4–13.6
Aeschynite	$R_2Nb_4O_{13}.R_2(Ti,Th)_5O_{13}$	21.2
Polymignite	$R(Nb,Ta)O_3)_3.5R(Ti,Zr)O_3)_3$	18.9
Euxenite	$R(NbO_3)_3.R_2(TiO_3)_3.\ \frac{3}{2}H_2O$	20.0–23.5

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† Varieties omitted.

TABLE I (*Continued*).

Mineral	Composition	Contains TiO_2, per cent.
Polycrase	$R(NbO_3)_3.\ 2R_2(TiO_3)3H_2O$	25.2–29.3
Blomstrandite	A niobate, tantalate and titanate of uranium	10.7
Dysanalyte	$6RTiO_3RNb_2O_6$	40.6–59.3
Strüverite	$FeO(Ta,Cb)_2O_5.\ 6TiO_2$ (?)	44.0
Epistolite	$Nb_2O_5.SiO_2.TiO_2.Na_2O.\ H_2O$(?)	7.2
Blomstrandine-Priorite	Niobates and titanates of Y, Er, Ce. and U	21.9–32.9
Marignacite	Same as pyrochlore	2.9
Ilmenorutile	$FeO,Nb_2O_5.5TiO_2$	53.0–73.8
Silicates:		
Amphibole	$CaR_3(SiO_3)4$. Variable amounts of TiO_2	As much as 8.5
Pyroxene	$CaR(SiO_3)_2$. Variable amounts of TiO_2	As much as 4.6
Biotite	$(H,K)_2(Mg,Fe)_4(Al,Fe)_2(SiO_4)_4$. Variable amounts of TiO_2	Variable up to 4.7
Lepidomelane	Iron mica, with variable amounts of TiO_2	Variable up to 4.7
Rosenbuschite	$6CaSiO_3.2Na_2ZrO_2F_2.(TiSiO_3.TiO_3)$	6.9–7.6
Titanolivine	Olivine $(Mg,Fe)_2SiO_4$ with variable TiO_2	3.5–6.1
Andradite	$Ca_3Fe_2(SiO_4)_3$; also $Ca_3Fe_2(Si, Ti)O_4)_3$ with variable TiO_2	Variable up to 10.8
Leucosphenite	$Na,Ba,(TiO_2)\ (Si_2O_5)_5$	13.2
Rhönite	$(Ca,Na_2K_2)_3Mg_4Fe_2Fe_3Al_4(Si,Ti)_6O_{30}$	9.5
Miscellaneous:		
Hydrotitanite	Altered form of dysanalyte	82.8
Warwickite	Perhaps $6MgO.FeO.2TiO_2 3B_2O_3$	23.5
Zirkelite	$(Ca,Fe)O.2(Zr,Ti,Th)O_2$	14.95
Derbylite	$6FeO.5TiO_2Sb_2O_5$	34.6
Lewisite	$5CaO.2TiO_2 3Sb_2O_5$	11.7
Mauzeliite	$4(Ca,Pb)O.TiO_2 2Sb_2O_5$	7.9
Hainite	Composition doubtful, probably allied to mosandrite	Undetermined
Senaite	$(Fe,Pb)O.2(Ti,Mn)O_2$. Uncertain	57.2

Titanium Ores.—A resurvey of the titanium ores is somewhat of an idle ceremony; however, the source of titanium commercially is confined exclusively to the titanium ores, there being but three at the present writing, viz., rutile, ilmenite, and titaniferous magnetite. That the latter has immense potentialities is the firm conviction of a number of metallurgists, although most of the investigations leading towards a method for their utilization have ended negatively. Many of the titaniferous magnetites are too low in titanium content to be now regarded as ores, although they might become so. As already alluded to in the foregoing, titanium is quite extensively distributed in sundry mineralogical forms, but the only ones of commercial value are those just mentioned. A great many other forms of titanium are either too rare, or too complex in composition, or are not found in sufficient quantity to be of value. Their interest chiefly is an academic one. To consider the ores of titanium specifically, it is found that of the many oxides of titanium occurring in nature but one of them is important as an ore; *i.e.*, rutile.

Rutile.—This mineral occurs as a pyrogenetic mineral in eruptive rocks, but it is more commonly found in gneiss, mica schist, and the phyllites. Rutile is also found as a secondary mineral, derived from ilmenite and titanite. It crystallizes in the tetragonal system commonly in prismatic crystals vertically striated or furrowed, and often acicular; it may be found also compact, massive to coarse and fine granular. Several kinds show marked and frequent twins. Composition, TiO_2 when pure. The mineral is brittle, with a hardness of 6 to 6.5, Mohr, and specific gravity 4.18 to 4.25 and up to 5.2 in a black variety with 10 per cent. FeO. The cleavage is distinct and the fracture subconchoidal to uneven; lustre is adamantine to metallic. Rutile is usually reddish-brown in color, passing into red; and it may be black, violet, yellowish, bluish, and very rarely grass green. The streak is pale brown. Rutile contains 40 per cent. oxygen and 60 per cent. titanium. Vanadium in disappearingly small amount and iron up to 10 per cent. are quite often present; at times chromium and tin are contained. The mineral is insoluble in acids and non-fusible under the blowpipe. It has a molecular volume of 19.1 and a molecular weight of 80.1. As referred to above, rutile is found in igneous, metamorphic, and sedimentary rocks. In the first named it may be either as an alteration product or a pyrogenetic constituent. In the metamorphic rocks, such as amphibolites, phyllites, gneisses, and mica schists, it is a common constituent, and it occurs more rarely in dolomite and granular limestone. Emmons[23] states that rutile is formed in igneous rocks, pegmatite dikes, contact metamorphic deposits, deposits of the deep vein zone, and as a product of dynamo-regional metamorphism. Rutile is an exceedingly stable mineral, but at times alters to leucoxene. Two other modifications of titanic oxide are brookite and anatase. Brookite alters into rutile, and rutile into ilmenite, anatase, and sphene, so that the titanium minerals are thus closely linked. The known distribution of rutile in commercial deposits is limited indeed. The more important ones are confined to two localities in Virginia, U. S. A., and one each in Canada, Europe, and Australia.

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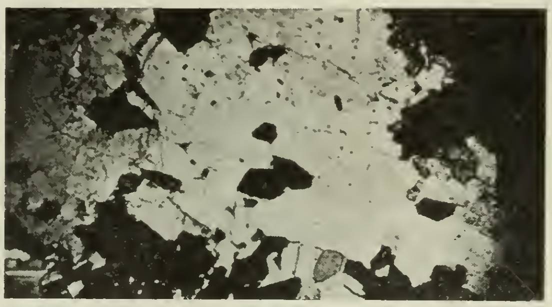
[23] Emmons, W. H., "A Genetic Classification of Minerals," *Econ. Geol.*, 1908, vol. iii, p. 621.

Rutile in Norway.—The most important locality at which rutile occurs commercially in Norway is near Kragerö, on the southeastern coast. As mentioned by W. C. Brögger and T. L. Watson,[24] the rutile here occurs in a large aplitic dike, referred to as rutile aplite. A thin section of the rock examined under the microscope shows feldspar, much rutile, quartz, and ilmenite in subordinate amount, as illustrated in Fig. 1.

FIG. 1.



Kragerite, a rutile-bearing aplite, from Kragerö, Norway. Black grains and crystals are rutile, light areas chiefly sodic feldspar (albite-oligoclase). Nicols crossed. × 30 diameters and reduced one-half. (After Watson and Taber.)

Rutile in Australia.—The only commercial occurrence of rutile in this country is near Mount Crawford, in South Australia, but other non-commercial occurrences are known. Little has been published on their geology. Hand specimens of ore from the leases of one F. J. Spence show chiefly a granular mixture of dark-red rutile and light silicate minerals, the principal ones of which include sillimanite, sericite, quartz, and, infrequently, feldspar. Broken and mashed sillimanite fibres, fractured rutile and quartz, etc., are some of the pressure effects of metamorphism revealed in the thin section, illustrated in Fig. 2.

Rutile in Virginia.—In "The Geology of the Titanium and

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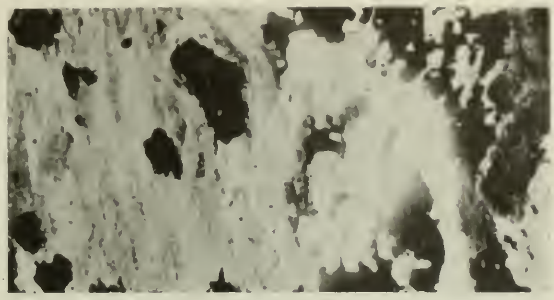
[24] Watson, T. L., "A Rutile-bearing Rock from Kragerö, Norway," *Am. Jour. Sci.*, 1912, vol. xxxiv, pp. 509–514.

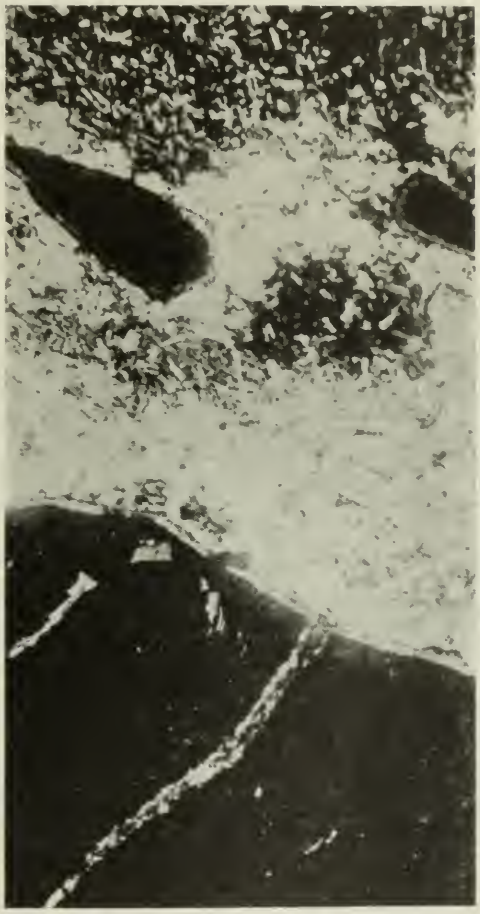
Apatite Deposits of Virginia," by Thomas L. Watson and Stephen Taber, the occurrences of commercial rutile ores are described at length and in a masterly manner; any mention in this place

FIG. 2.



Rutile-bearing pegmatite (?) from South Australia. Black areas rutile, light areas in right half of figure feldspar and quartz, medium-gray and light fibrous areas in left half sillimanite. Nicols crossed. × 30 diameters and reduced one-half. (After Watson and Taber.)

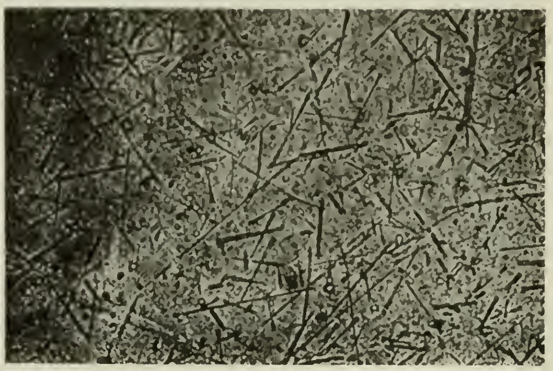
FIG. 3.



Rutile-bearing syenite, American Rutile Company's quarries at Roseland, showing rutile (the two dark grains in upper part of figure and the mass in lower half) rimmed by the alteration product leucoxene. Note the same alteration product filling fracture crossing rutile mass in lower half of figure. Nicols crossed. × 30 diameters (After Watson and Taber.)

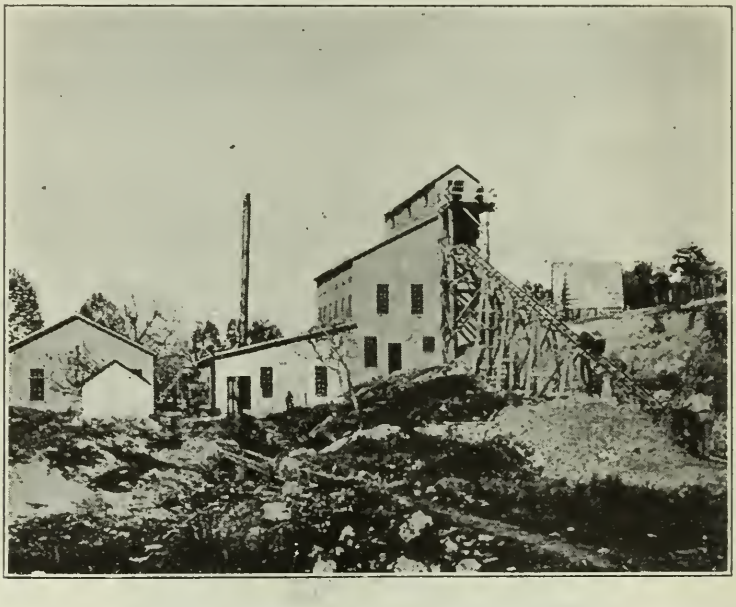
seems superfluous. However, sufficient to say that the Virginia deposits are of particular interest because of their scientific and commercial importance. They are the only known workable rutile deposits in this country. The rutile area of Virginia lies in Amherst and Nelson counties, about half way between Charlotteville and Lynchburg. Practically the entire production of rutile in the state has been turned out by the American Rutile Company at Roseland; the mill of the company has seen more or less intermittent operation, due to market conditions. Without going into detail, the rutile-bearing rock of the American Rutile Company's property is a syenite. A micro-thin section

FIG. 4.



Blue quartz in syenite filled with inclusions of rutile needles. General Electric Company's mine. Nicols crossed. X 375 diameters and reduced one-half. (After Watson and Taber.)

FIG. 5.



Mill and surface plant of the American Rutile Company, Roseland. (After Watson and Taber.)

(see Fig. 3) shows typically the secondary alteration production leucoxene, as well as the dark rutile. Rutile as microscopic hairlike inclusions is abundantly developed in the quartz in some places; this is typically shown in Fig. 4. Most of the rutile mining has been carried on by the American Rutile Company, at its Roseland mill, shown in Fig. 5.

There are given in tabular form in Table II analyses of typical rutile concentrates produced by the company. The concentrates naturally fall into two divisions by reason of their treatment; viz., those treated by magnetic machines, and those not so treated. The difference in treatment reveals itself in the analyses; those concentrates not treated magnetically showing low titania and high iron, and *vice versa*.

TABLE II.[25]

Commercial Analyses (Partial) of Rutile Concentrates From the American Rutile Company's Property.

No.	TiO_2	Fe.	SiO_2	Analyst
1....	99.22	0.44	....	Waller and Renaud, New York City.
2....	98.60	0.40	1.20	General Electric Company's laboratory, Schenectady, N. Y.
3....	98.42	0.48	....	Waller and Renaud, New York City.
4....	97.54	1.17	....	Ricketts and Banks, New York City.
5....	96.50	0.42	0.77	Waller and Renaud, New York City.
6....	95.18	1.28	....	Ledoux and Company, New York City.
7....	94.65	2.15	....	Simonds and Wainright, New York City.
8....	94.47	2.76	0.51	Waller and Renaud, New York City.
9....	94.34	4.05	....	Waller and Renaud, New York City.
10....	94.12	1.58	....	Waller and Renaud, New York City.
11....	93.22	2.26	....	Ledoux and Company, New York City.
12....	93.14	4.40	....	Waller and Renaud, New York City.
13....	92.94	5.46	....	Waller and Renaud, New York City.
14....	91.24	8.02	....	Waller and Renaud, New York City.
15....	90.58	5.82	....	Waller and Renaud, New York City.
16....	90.10	5.01	1.95	Simonds and Wainright, New York City.
17....	89.91	3.46	....	Ledoux and Company, New York City.
18....	89.85	8.85	....	Waller and Renaud, New York City.
19....	89.30	7.33	0.70	Waller and Renaud, New York City.
20....	89.08	2.99	....	Ledoux and Company, New York City.
21....	88.73	7.06	....	Waller and Renaud, New York City.
22....	88.08	9.45	....	Waller and Renaud, New York City.
23....	87.16	7.33	0.44	Waller and Renaud, New York City.
24....	86.18	8.24	....	Ledoux and Company, New York City.
25....	85.90	9.60	....	Ledoux and Company, New York City.
26....	85.60	10.92	....	Waller and Renaud, New York City.

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[25] Watson, T. L., and Taber, S., "Geology of the Titanium and Apatite Deposits of Virginia," Bull. III-A, Virginia Geological Survey, p. 173.

Ilmenite.—This is the only one of the many titanites which is important as an ore of titanium. It is a heavy, black mineral crystallizing in the hexagonal system, being rhombohedral. The chemical composition is very variable; if normal, the formula is $FeTiO_3$, corresponding to 47.3 per cent. FeO and 52.7 per cent. TiO_2. There is an isomorphous series, $(Fe,Ti)_2O_3$, with varying amounts of iron and titanium grading down to hematite (Fe_2O_3). Rarely are good megascopic crystals of ilmenite observed; the mineral normally is seen as embedded grains and in masses, although often as irregular plates, and as sand; *e.g.,* in the black sand at Menachan, Cornwall. The cleavage is obscure and the fracture is conchoidal. Ilmenite is brittle, with a hardness of 5 to 6 and a specific gravity of 4.5 to 5.0. The color is iron black, but it occasionally shows a brownish or reddish tinge. The streak is black to brownish-red. Usually it is slightly magnetic, but not always. The molecular weight is 152, and the molecular volume 30.4. In nature, ilmenite is widely diffused, occurring as an essential constituent in diorite, gabbro, diabase, and basalt, and related rocks. It is isomorphous with, or occurring with, hematite in granite and syenites.[26] In many metamorphic rocks, as amphibolites, mica schist, and gneiss, particularly, is ilmenite found. According to Lindgren[27] and Emmons,[28] ilmenite is formed in igneous rocks, in pegmatites, in contact metamorphic deposits, in deep veins, and under regional-metamorphic actions. The mineral has been little investigated on the synthetic side, but its constitution has been much discussed.

Titaniferous Magnetites.—The importance of the titanium-bearing magnetites is such that a separate division of this writing immediately following is devoted to their consideration.

4. TITANIFEROUS MAGNETITES.

In General.—American and other ironmasters are confronted with the important problem of the reduction on a large scale of titaniferous magnetites containing titanium in large amount. Large bodies of easily mined titanium-bearing magnetites have been discovered from time to time, and a voluminous mass of contemporaneous literature is at hand dealing with their geological occurrence and probable economic value. The approach, in the not far distant future, of the possible exhaustion of the deposits of non-titaniferous iron ores, and the use in blast-furnace plants now of lower tenor iron ores than formerly, point the way to the necessity of some time turning to the titanium-bearing material for smelting. The general feeling among works managers is that iron ores containing in excess of one per cent. of titanium are difficult to smelt in the furnace, in spite of the demonstrations of Rossi and other workers to the contrary. It appears, according to the experiments of Rossi, that titanium may be eliminated by producing comparatively fluid titano-silicate slags. Still, there is little hesitancy on the part of furnace men in stating that they cannot change their practice in order to conform to such requirements. Dr. J. T. Singewald, Jr., in an able dissertation,[29] points out the feasibility of using the concentrates from a magnetic process for treating titaniferous ores in a blast-furnace mixture with high-grade hematite. The reduction of titanium-rich ores by electric smelting is a problem of importance and has the serious consideration of those interested in their being used. The milling problem is one that is more annoying than is generally supposed, by reason of the manner of occurrence of the titanium in the ores. Off-hand it would seem as though magnetic separation would effectively separate the ilmenite and the magnetite. Micrographic examination has shown that the ilmenite in most of the large deposits occurs in such fine intergrowths that a clean separation of the two minerals cannot be effected by any method employing variation in their physical properties. In a word, the problem is metallurgical and involves a direct smelting of the ores.

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[26] Clarke, F. W., "The Data of Geochemistry," U. S. Geological Survey, Bull. 616, p. 348.

[27] Lindgren, W., "The Relation of Ore Deposits to Physical Conditions," *Econ. Geol.,* 1907, vol. ii, p. 125.

[28] Emmons, W. H., "A Genetic Classification of Minerals," *Econ. Geol.,* 1908, vol. iii, p. 621 *et seq.*

Mineralogy and Geology of Titaniferous Magnetites.—The manner in which titanium occurs in titaniferous magnetites is a question of importance; it is one which has been discussed at great length, and one on which divergent opinions have been expressed with great freedom. Previous to the work of Singewald [30] there had been but little systematic scientific attempt made to solve the problem. Some writers claimed that the ores were mechanical aggregations of magnetite and ilmenite; others stated that the titanium was a part of the magnetite molecule, replacing a part of the iron. Regardless of which view is correct at this juncture, let it be said that the question is one of keen practical import, and not one merely of academic interest. If, as has been stated, titanium is part of the magnetite molecule, no process of mechanical separation can successfully work. If, on the other hand, as has been claimed by some, the ores are aggregates of magnetite and ilmenite, such separation is possible; since magnetite is strongly magnetic, and ilmenite only feebly so or not magnetic at all, crushing followed by treatment on a magnetic separator should separate the two. A great many experiments on different ores have been made employing magnetic processes, and varying degrees of success have been obtained. At any rate, the tests appear to indicate that the ores consisted of aggregates of magnetite and ilmenite to a varying extent; they demonstrated also that the magnetite grains contained titanium. Singewald picked out grains of magnetite so separated, showing no ilmenite intergrowths on etching, and found by analysis that such grains showed an appreciable titanium content, and, in one

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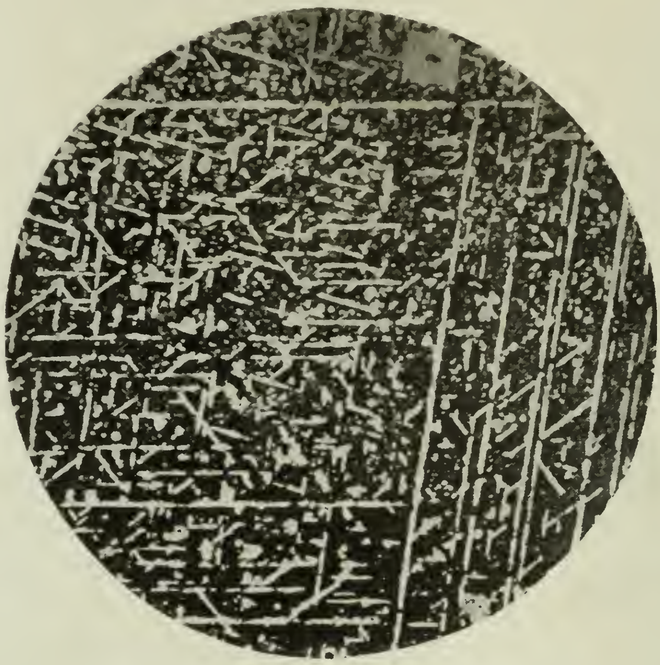
[29] Singewald, J. T., Jr., "The Titaniferous Iron Ores of the United States," Bull. 64, Bureau of Mines, 1913.

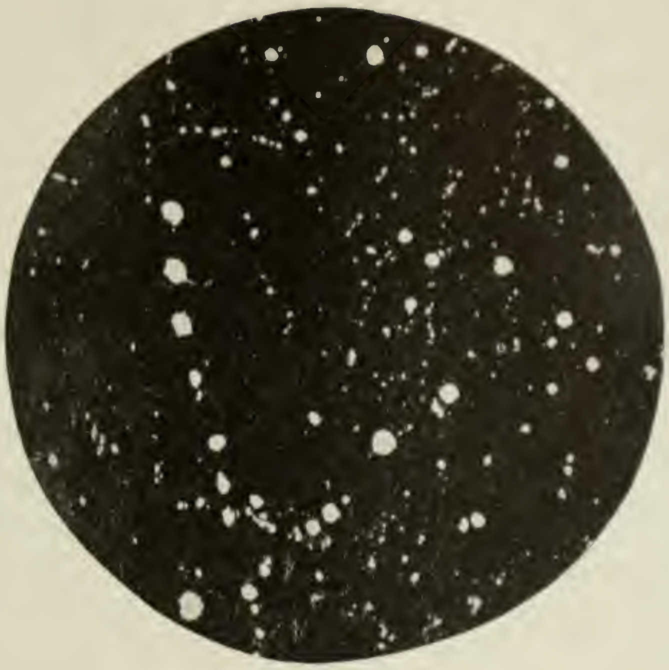
[30] Singewald, J. T., Jr., "The Microstructure of Titaniferous Magnetites," *Econ. Geol.*, vol. viii, No. 3, April–May, 1913, p. 207 *et seq.*

FIG. 6.



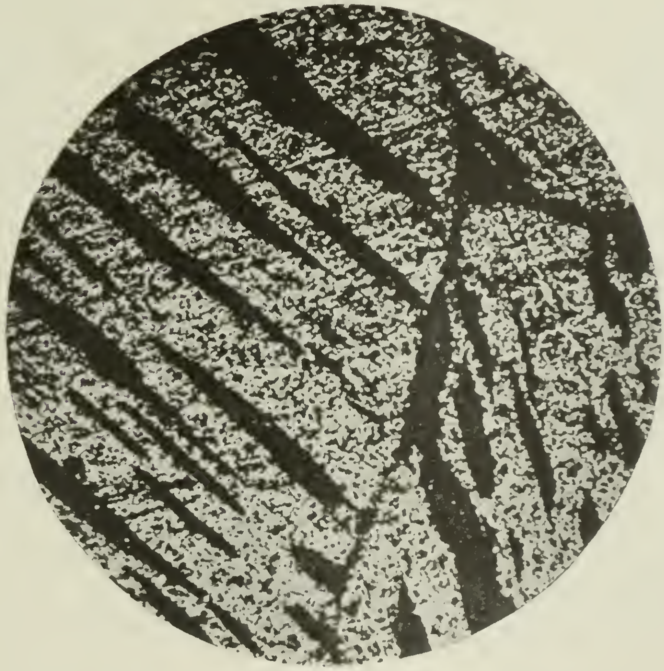
Lines show sections of minute ilmenite lamellæ, oriented parallel to the octahedral face of the magnetite. X 60 diameters. (After Singewald.)

FIG. 7.



Dot intergrowths of ilmenite showing rectilinear orientation parallel to the octahedral magnetite cleavages. × 60 diameters. (After Singewald.)

FIG. 8.



Lenticular bands of magnetite in ilmenite. × 60 diameters. (After Singewald.)

case, 6.6 per cent. Ti. This points to the existence of a titano-magnetite. Singewald aptly points out in *résumé:* "Titaniferous magnetites consist of granular aggregates of magnetite and ilmenite. The magnetite is usually not homogeneous, but contains minute intergrowths of ilmenite in both regular and irregular orientation, and may contain a considerable percentage of titanium in the magnetite molecule itself."

On examination of black magnetite ores under the microscope, it may be readily observed that, in some cases, they are non-homogeneous and contain minute ilmenite intergrowths. The most commonly noted forms of such intergrowths are as lines and dots showing in the section. Such line intergrowths are seen in Fig. 6; dot intergrowths showing in approximately circular outline are seen in Fig. 7. Another form of intergrowth is that noted in certain Canadian ores, consisting of a banded lenticular arrangement, seemingly bands of magnetite in grains of ilmenite. According to Singewald, the structure suggests a magnetite-ilmenite eutectic structure. This latter is strikingly revealed in Fig. 8.

Occurrence of Titaniferous Magnetites.—This subject has been treated at length in the current technology by such writers as Johnson and Warren,[31] Jackson,[32] Wadsworth,[33] Dana,[34] Kemp,[35] Newland,[36] Bayley,[37] Nitze,[38] Winchell,[39] *et al.* The most recent summation is the able treatise of Singewald, referred to earlier in the text. Suffice it to say that the deposits are widely diffused, but occur in workable deposits at but two places in this country; viz., those at Lake Sanford, New York, and at Iron Mountain, Wyoming. The ores are nearly pure aggregates of magnetite and ilmenite, the roughly estimated tonnage of each running into millions (no accurate estimate has been made). The other titaniferous iron ores in the United States cannot be figured as sources of iron for many years, seemingly almost indefinite at the present writing. In view of the excellent work of Singewald, it appears a useless task to recall the data further in this short work.

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[31] Contributions to the Geology of Rhode Island: I. "Notes on the History and Geology of Iron Mine Hill, Cumberland," by B. L. Johnson. II. "The Petrography and Mineralogy of Iron Mine Hill, Cumberland," by C. H. Warren; *Am. Jour. Sci.*, 4th ser., vol. 25, January, 1908, pp. 1–38.

[32] Jackson, C. T., "Report on the Geological and Agricultural Survey of the State of Rhode Island," 1840, p. 52.

[33] Wadsworth, M. E., "A Microscopic Study of the Iron Ore or Peridotite of Iron Mine Hill, Cumberland, R. I.," Mus. Comp. Zool., Harvard College Bull. 7, 1881, pp. 183–187, and "Lithological Studies," Mem. Mus. Comp. Zool., Harvard College, vol. ii, 1884, p. 80.

[34] Dana, J. D., "Iron Ore of Iron Mine Hill, Cumberland, R. I.," *Am. Jour. Sci.*, 3d ser., vol. xxii, 1881, p. 152.

[35] Kemp., J. F., "The Titaniferous Iron Ores of the Adirondacks," 19th Annual Report U. S. Geol. Survey, pt. 3, 1899, pp. 377–422.

[36] Newland, D. H., "Geology of the Adirondack Magnetic Iron Ores," N. Y. State Mus. Bull. 119, pt. 3, 1908, pp. 152–156.

[37] Vol. 7 of the final report series of the State Geologist, 38, New Jersey, 1910.

[38] Nitze, N. B. C., "A Preliminary Report on the Iron Ores of North Carolina," North Carolina Geol. Survey, Bull. 1, 1893.

[39] Winchell, H. V., "Seventeenth Annual Report of the Geological and Natural History Survey of Minnesota," 1888, pp. 80–81.

Smelting of Titaniferous Magnetites: IN GENERAL.—In spite of prolix discussion at periodic intervals, the problem of smelting the titaniferous iron ores in the blast furnace as yet remains unsolved to the satisfaction of most metallurgists. Most realize that such ores have been smelted with marked success, but, in the main, the consumption of fuel for their reduction has been so high that the cost is well-nigh prohibitive. Ores containing over one per cent. of titanium are condemned as unsuitable for part of the blast-furnace burden mainly on account of the high fuel consumption, and, further, by reason of the formation of accretions and the production of scaffolding in the furnace, thereby choking the operation. A hasty survey shows that the consumption of such ores has greatly fallen off; nor is this to be wondered at, in view of the condition of the iron industry years ago and now.

Blast Furnace Smelting.—Disregarding here the pros and cons of the question, it appears that the titaniferous ores will in time find a place in the industry. Their great tonnage magnitude, as well as their ease of workability and freedom from sulphur and phosphorus, makes them highly desirable, particularly for Bessemer practice. At some furnace plants in Norway, Sweden, and England titaniferous iron ores were smelted as such in late years; at some plants titaniferous ore was admixed with non-titaniferous material to form the smelting charge. The deposits at Taberg, Sweden, were worked extensively for a number of years over a century ago, but their use has been practically abandoned with the introduction of the modern blast furnace. A furnace operated at Lake Sanford, New York, for sixteen years, beginning in 1840, but this, too, has ceased activities. In 1873 the Canadian Titanic Iron Company built two blast furnaces near Bay St. Paul, but their life was of short duration.[40] In view of the high fuel consumption (*i.e.*, from 3000 to 6000 pounds, approximately, of charcoal per ton of iron), it is surprising that the work lasted as long as it did. Wherever the smelting of such ore has been tried the process has been a perfect technical success, but the high fuel consumption has made it impracticable commercially.

In this country the indefatigable investigator, A. J. Rossi, has made a thorough study of the problem and has set forth his results in several writings, his first review of the work being given out in 1890.[41] Rossi conducted extensive experiments with a view to making the smelting of titaniferous magnetites a commercial success. The best results were obtained by forming a tribasic slag of lime, magnesia, and alumina. The ores charged analyzed from about 18 to 20 per cent. TiO_2 and yielded good pig iron and readily fusible slags showing proper fluidity. Rossi's later experiments were particularly conclusive; still, no attempts have been made to follow out his lines of work on a large scale, and the ores are as yet in bad repute. Rossi's experiments[42] followed those first carried on by Forbes,[43] who was connected with the iron industry in southern Norway; *i.e.*, they were first for the purpose of finding easily fusible titanate slags.

In a summation of the results of his work Rossi very properly resumes:

1. "As anybody who may desire to make the experiment can verify, titanic acid can form definite compounds, perfectly fusible, if properly fluxed, containing as much as 35 to 40 to 50 per cent. of titanic acid, with alumina, lime, and magnesia as bases, and admissible as slags in blast-furnace work. Larger percentages still, such as 65 per cent., can enter into a compound and it remains fusible. The objections to the smelting of titaniferous ores on

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[40] Harrington, B. J., "Notes on the Iron Ores of Canada, and Their Development," Geol. Survey Can., Report of 1873–74, pp. 249–251.

[41] Rossi, A. J., "Titanium in Blast Furnaces," *Jour. Am. Chem. Soc.*, vol. 12, 1890, pp. 90–117.

[42] Rossi, A. J., "Titaniferous Ores in the Blast Furnace," *Trans. A. I. M. E.*, 1893, vol. 21, pp. 832–864, and "The Smelting of Titaniferous Ores," *Iron Age*, i, 1896, pp. 354–356 and 464–469.

[43] Forbes, David, "On the Composition and Metallurgy of Some Norwegian Titaniferous Iron Ores," *Chem. News*, 1868, pp. 275–276.

account of the refractory character of the slags are not sustained by our practice or that of others, or by direct experiments on the properties of these compounds.

2. "In running a furnace under special conditions of temperature and pressure of blast no troubles have been experienced from the titanium deposits. We never observed any in our blast-furnace tests, and none are mentioned by Doctor Forbes in his practice in England and Norway.

3. "If these special conditions of lower heat, considered more favorable in smelting these ores, are held to imply against them a waste of fuel, it is a question whether this is not offset by the smaller amount of cinder to melt, the lesser quantity of fluxes necessary, and their indirect effect upon the productive capacity of the furnace, as well as the greater value of the pig metal obtained for specific and numerous applications. This is without taking into account the possibility of not submitting to it by a rapid driving and forcing the production, conditions which, to judge from our tests, could be easily realized with these ores."

Electric Furnace Smelting.—Direct smelting of iron ores by an electric furnace process is one whose full potentialities have as yet not been shown. In some quarters its success has been signal; still the knowledge *in toto* is so incomplete that final conclusions cannot be drawn. Experiments with the electrical reduction of titaniferous iron ores have been conducted by a number of workers at many places, but particularly of late by Eugene Haanel[44] in Canada. In 1907 a series of experiments was performed on an ore analyzing 17.82 per cent. TiO_2: the experiments were incomplete, so that the results were negative. Borchers[45] has discussed the investigations carried out at his Aachen laboratory. Tests have been carried on here for over twelve years with the object in view of reducing the iron and recovering the titanium. Leyner, in 1898–99, and Hupperty, in 1904, also worked along similar lines in Germany. Gustave Gin[46] treated titaniferous iron ores from Norway in the electric furnace at the electrochemical plant at Jessains, Department of Aube, France, in 1901. His conclusions from the experiments are that the electrical reduction of titaniferous iron ores presents no special difficulties, and that the problem is a question of abundant and cheap water power.

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[44] Haanel, Eugene, "Report on the Experiments Made at Sault Ste. Marie, Ontario, under Government Auspices, in the Smelting of Canadian Iron Ores by the Electrothermic Process," Canadian Department of Mines, Mines Branch, 1907, pp. 85–86.

[45] Borchers, W., "Titaniferous Iron Ores: Smelting in the Electric Furnace," *Stahl und Eisen*, May 4, 1911, p. 1706.

[46] Gin, Gustave, "On the Electrical Reduction of Titaniferous Iron Ores." *Trans. Am. Electrochem. Soc.*, 1907, vol. xi, p. 291 *et seq.*

Stansfield[47] has experimented considerably in this field, and some abstracted remarks from his writings are quoted:

" Although the possibility of the electric smelting of iron ores for pig iron cannot be definitely settled in a general way, there appears to be every probability that a process which yields steel instead of pig iron would be commercially possible in favorable localities. Steel could be made by smelting titaniferous iron ores in an electric furnace with a somewhat smaller amount of charcoal than would be needed for making pig iron, and the resulting metal could be transferred in the molten condition to an electrical steel refining furnace, where it could be made into finished steel. The cost of producing the crude steel from the ore would be a little more than that of producing pig iron, and the cost of refining the steel would be only a moderate addition to this, while the price obtainable for the finished product would be decidedly higher than could be obtained for pig iron.

" The writer has been associated with Mr. J. W. Evans in the development of a process in which the reduction of titaniferous ores to metal and the subsequent refining of the steel is carried out in a single furnace, and, while the details of the furnace construction and certain parts of the operation have not yet been fully worked out, the results have been so encouraging that it appears to be worth while to develop the process on a small working scale. With regard to the results so far obtained, it may be stated that titaniferous ores obtained from the Orton mine and containing about 7 per cent. of titanium have been smelted directly to steel, and that such steel, containing about one per cent. of carbon, has been found to possess unusually good qualities as a tool steel. The cost of smelting these ores and refining the steel can be determined fairly accurately from the figures published in regard to the electrical smelting of iron ores to pig iron and the electrical refining of molten steel. These figures are more dependable than data obtained from the small-scale experiments that have so far been made. The writer intends, however, in the near future to make further experiments on the reduction and refining of the steel in order to obtain direct information as to the cost of the process.

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[47] Stansfield, Alfred, " Electric Smelting of Titaniferous Ores," *Can. Min. Jour.*, vol. 33, 1912, pp. 448-449.

"There do not appear to be any definite limits as regards the percentage of titanium in ores suitable for this process, but the cost of smelting will, of course, increase with the proportion of titanium, both on account of the cost of fluxing it and on account of the smaller proportion of steel obtained. It seems probable, therefore, that the process will be applied to ores that do not contain more than 5 to 10 per cent. of titanium. Ores somewhat richer than this in titanium may be concentrated magnetically, so as to obtain a product which shall be at once richer in iron and poorer in titanium, and it may even be possible in some cases that the tailings from such a concentration process may be sufficiently rich in titanium to be smelted for ferro-titanium. Some ores containing too much titanium for steel making are not amenable to magnetic concentration, and these may be smelted with suitable admixture of non-titaniferous ores. It has been found that the electric furnace is more suitable than the blast furnace for the treatment of pulverized ores, and that magnetic concentrates can be smelted alone or with the addition of a moderate proportion of coarser ore.

"The use of titaniferous ores for making tool steel would appear to be very advantageous commercially, but cannot be expected to provide for a large consumption of these ores, and it is of interest to consider whether the process can be applied to the production of steel on a larger scale. One purpose for which this process would appear to be very suitable is for the production of steel castings. A good deal of difficulty is experienced in the production of steel castings which can be relied upon as being entirely sound, and ferro-titanium is used in some cases for producing soundness in steel castings. It seems very probable, therefore, that steel made directly from titaniferous ores will be particularly suitable for the production of steel castings, and this will afford a larger field for the electric smelting of these ores. With regard to the use of this process on a still larger scale—for the production of steel rails, for example—the writer would say that there appears to be no definite reason why rails should not be made by this process, but would not care to speak definitely with regard to this until the process has been in operation on a working scale."

From the foregoing it may be observed that there has been no dearth of workers in this field of investigation; the reward for the solution of the problem promises to be rich.

5. USES OF TITANIUM AND ITS COMPOUNDS.

General Statement.—Certain compounds of titanium have long enjoyed use, though in limited amounts, mainly as refractory coloring agents in ceramics. The pure element has not been used to any extent, because of its high melting-point, but titanium alloys have of late found rather far-reaching employment in the metallurgy of the non-ferrous metals, as well as in iron and steel. Recent developments in the use of the electric furnace, with its concomitant high temperatures, have encouraged the exploitation of processes for the reduction of titanium from its mineral ores, as well as the manufacture of titanium alloys on a large scale.

A better classification than that of Watson and Taber [48] concerning the useful products in which titanium is an important constituent can scarcely be made, viz.:

A. Metallic alloys, such as ferro-titanium and cupro-titanium.
B. Incandescent media for lighting purposes, including gas mantles, arc-lamp electrodes, and filaments for incandescent electric lamps.
C. Mordants and dyes for leather and textiles.
D. Refractory coloring material for use in ceramics and the manufacture of artificial teeth, and
E. Miscellaneous.

These uses are considered in the following pages, with some attempt to allot space according to the relative importance of the same.

A. METALLIC ALLOYS OF TITANIUM.—Quite a large number of binary and a few ternary titanium alloys have been investigated, but the only alloys on the market for commercial consumption are ferro-carbon titanium, ferro-titanium, cupro-titanium, and mangano-titanium. The alloys of titanium with iron were the first to receive marked attention, and of late years their use has increased largely, particularly by reason of their being employed as purifiers in iron and steel metallurgy. The present presence of titanium as an active agent in the iron and steel industry is directly due to the labors of A. J. Rossi, the dean of American titanium investigators, who has devoted some thirty years in this field. In Germany, H. Goldschmidt brought out the first successful, practical process for the reduction of titanium from its ores by means of his now well-known alumino-thermic method.

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[48] Watson, T. L., and Taber, S., Bull. III-A, Virginia Geological Survey, 1913, p. 271.

Ferro-carbon Titanium.—This alloy, for use as a final deoxidizer in iron and steel metallurgy, is a product manufactured in this country by The Titanium Alloy Manufacturing Company, Niagara Falls, N. Y., and it is a development resulting from the introduction of the electric furnace for ferro-alloy production. Rossi's work leading up to the production of what is known as ferro-carbon titanium is summed up in the following: In 1892 he secured a patent pertaining to the reduction of titaniferous ores in the blast furnace; a little later he tried to produce a ferro-titanium alloy in the blast furnace and crucible, but was unable to secure an alloy showing high titanium content. Experimental work conducted with the electric furnace resulted in the production of a commercial ferro-titanium alloy for use in steel making. In the Rossi process the reduction takes place in a bath of aluminum, the aluminum as ingots or any other convenient form being melted in the electric furnace. Pig iron or scrap iron is next added to the charge, and then rutile is introduced into the bath; the temperature is raised to such a point necessary to start the reaction whereby the aluminum combines with the oxygen of the rutile. The rutile is thus reduced to metallic titanium and alloys with the iron. The resulting alloy is practically carbon-free.

In case ilmenite or titanic iron ore is used in place of rutile, a great deal more aluminum is required to reduce the ferric oxide, thus increasing the cost of manufacture, because the iron can be otherwise more economically reduced. Where the alloy is prepared by reducing oxide of iron and titanium with carbon in the electric furnace, the product will contain from 5 to 9 per cent. carbon, mainly in the form of graphite. Carbon is at present used exclusively for the reduction by The Titanium Alloy Manufacturing Company, replacing the aluminum bath method, once used. The process is described at length in letters-patent, domestic and foreign. In Rossi's first patent[49] he specified the reduction of titaniferous ore and rutile by means of carbon in an electric-resistance furnace with the production of a ferro-alloy containing over 5 per cent. titanium and some carbon, the reduction occurring in a bath of molten iron. Titaniferous slag was to be treated in the manner just described in a similar patent.[50] Two years later he patented[51] a process calling for the reduction of titaniferous ores in a bath of molten reducing metal (*e.g.*, aluminum), as alluded to above, in the electric furnace. In 1901 he procured a patent[52] for the concentration of titanium in slag by the reduction of the silicon and iron of a titaniferous ore with carbon, the temperature of operation to be below the fusion point of titanium oxide (TiO_2).

At one plant ferro-carbon titanium is produced commercially in a Siemens electric furnace of 500-kilowatt size. Titaniferous ore, or slag, or rutile is introduced, mixed with the proper amount of carbon, onto the top of a molten bath of scrap iron or steel. The reduction takes place in the arc, and the product is tapped off. The titaniferous ore charged has this analysis: 34.36 per cent. TiO_2, 50.53 per cent. FeO, 4.14 per cent. SiO_2, and 2.20 per cent. Al_2O_3. Slag from the process, if high in titanium, is recharged. The product obtained from the reduction analyzes 10 to 15 per cent. Ti, 5 to 8 per cent. C, and 0.35 to 1.00 per cent. Si. If this alloy be refined, employing rutile as a decarbonizing agent, a product is secured analyzing 10 to 15 per cent. Ti, 0.35 to 1.00 per cent. Si, and less than 1 per cent. C. In order to cut down the titanium lost through volatilization, Rossi, in a late patent,[53] calls for the introduction of lime (CaO) onto the molten iron bath, following this with titanic oxide, lime, and carbon; this causes a reaction with the reduction of metallic titanium as follows:

$$TiO_2 + CaO + 5C = Ti + CaC_2 + 3CO$$

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[49] U. S. Patent No. 609,466, August 23, 1898.

[50] U. S. Patent No. 609,467, August 23, 1898.

[51] U. S. Patent No. 648,439, May 1, 1900.

[52] U. S. Patent No. 668,266, Feb. 19, 1901.

[53] U. S. Patent No. 1,019,528, March 5, 1912.

The merit of ferro-carbon titanium and its use in iron and steel metallurgy will be dealt with a little later on.

Ferro-titanium.—By ferro-titanium is meant the binary alloy free from carbon as produced by the Goldschmidt Thermit Company. As already alluded to, a process by Rossi accomplishes the same thing. Both processes depend on the strong reducing power of metallic aluminum. In the Goldschmidt process the metallic oxides which are to be reduced are mixed with aluminum in the proper amounts, both oxides and the metal being in a finely powdered state. Ignition with a fuse brings some point of the mixture to the temperature at which aluminum and oxygen combine. Once started, the reaction proceeds to completion with the concomitant reduction of the oxides. The high cost of aluminum powder and the difficulty of securing a pure product are objections to the process. The reaction which takes place is according to the following:

$$3\ TiO_2 + 4\ Al = 3Ti + 2Al_2O_3$$

The reaction may also be started over a molten iron bath by the heat thereof. The product produced by the Goldschmidt thermit process contains from 5 to 6 per cent. Al alloyed with the titanium. This alloy has been used for a number of years in many European steel works as a final deoxidizer in casting practice. In a late patent [54] granted to Drs. Hans Goldschmidt and O. Weil, of Germany, assigned to the Goldschmidt Thermit Company, alloys higher in titanium are made. The purpose of these alloys is to provide a modicum for adding a higher percentage of titanium to iron and steel baths, thereby overcoming otherwise alleged objections to low titanium content alloys. These alloys contain 15 to 35 per cent. Ti, 1.5 to 3.5 per cent. Al, and the remainder Fe. The aluminum lowers the melting-point of the titanium by combining therewith to form a titanium-aluminum alloy, the alloying qualification being thereby increased, so it is stated. The titanium alloys when made by the alumino-thermic process are more expensive than those made in the electric furnace, and this is a cogent factor militating against their use.

The Ferro-carbon Titanium-Ferro-titanium Controversy.—Noting what has been said regarding the two alloys (*i.e.*, ferro-carbon titanium and ferro-titanium) being used in the metallurgy of iron and steel and being manufactured by rival companies, it is no small wonder that the technical press has been deluged with arguments as to their merits. In view of the importance of the subject, the merits of the two alloys will be dealt with here. Before setting forth the respective claims of the supporters of each, it would seem that the whole question hinges on the matter of alleged carbides in the electric-furnace product, which have been claimed to prevent its ready solution in steel, so that it would not appear in that light to do the work of the carbon-free alloy. Yet there does not appear to be over 0.25 per cent. of combined carbon in the alloy containing as much as 9 per cent. carbon. The carbon is mostly in the form of graphite, and, on adding the alloy to the steel or iron, part of the carbon combines with the iron, forming Fe_3C, iron carbide, while the remainder is removed in the slag by rising to the surface of the bath.

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[54] U. S. Patent No. 1,136,670, April 20, 1915.

At any rate, metallurgists have practically all agreed that the use of a small percentage of titanium in some form is of benefit to iron and steel, and to-day titanium alloys are used in practically every grade of steel, both low and high carbon, alloy and other special steels, and in iron. Doctor Goldschmidt [55] has made the statement that the carbon-free metals dissolve with greater ease than those same metals containing carbon, because the carbon is present in the form of carbides in the latter. Charles V. Slocum found that the carbon-free alloy was not at all adapted to the metallurgy of iron and steel in the rôle of a deoxidizer and purifier. The company he is connected with was forced to produce an alloy containing 5 to 8 per cent. carbon for this use. According to Mr. Slocum, the Rossi interests early put on the market a carbon-free ferro-titanium alloy which was illy received by users, and which was a complete failure. The cause of this is attributed to the presence of the aluminum, which not only made the steel brittle, but also tended to the formation of oxides, which were retained as inclusions in the metal.

In this country, what is referred to by the trade as "titanium alloy" is usually the ferro-carbon titanium alloy of The Titanium Alloy Manufacturing Company. The alloy contains from 5 to 8 per cent. carbon, mostly in the form of graphite, the combined carbon being present in small amount—in fact, disappearingly so. Analyses given in Table III show the relative amounts of combined and graphitic carbon made on four samples of the alloy.

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[55] Goldschmidt, Hans, "The Melting-point and its Relation to Alloying Capacity." *Met. and Chem. Eng.*, 1911, vol. ix, p. 348.

TABLE III.

*Analyses of Ferro-carbon Titanium.**

Sample	Graphite	Combined carbon
1	9.601	0.147
2	9.179	0.120
3	7.012	0.130
4	6.234	0.118

*After The Titanium Alloy Manufacturing Company, Niagara Falls, N. Y.

The alloy of the above company is guaranteed to contain at least 15 per cent. titanium and has an average analysis as follows:

Ferro-carbon Titanium.

Silicon	1.41 per cent.
Titanium	15.79 per cent.
Carbon	7.46 per cent.
Manganese	0.11 per cent.
Aluminum	0.80 per cent.
Phosphorus	0.05 per cent.
Sulphur	0.08 per cent.
Iron (by difference)	74.30 per cent.
	100.00 per cent.

It is held by some that titanium acts much as does silicon in the manner of throwing carbon out of combined form into the graphitic state, and there is no ground for the belief that the carbon present in the triple alloy is mainly there as combined carbon. George B. Waterhouse,[56] who has used considerable quantities of this alloy in Lackawanna practice, draws attention to an interesting incident: Iron for the production of malleable castings was treated in the ladle with a titanium alloy, and the poured metal showed on fracture a white border from 1 to 1.25 cm. thick and a gray centre, indicating the presence of graphite; the same metal not so treated showed a fracture perfectly white, with very little gray in the centre. The density of deoxidizers, used as the titanium alloys are used, has an important bearing on their proper incorporation in the molten bath. The density of the 10 to 15 per cent. ferro-carbon titanium is from 6.20 to 6.40, being approximately the same as the Goldschmidt product.

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[56] The Lackawanna Steel Company, Buffalo, N. Y.

In support of the other alloy, Doctor Goldschmidt claims that the ferro-titanium containing aluminum, as made by his company, is a far better and more efficient agent than the lower percentage titanium alloy containing carbon. His contention is that the aluminum is requisite and essential. In replying to Mr. Slocum's remarks in a discussion in the proceedings[57] of the American Electrochemical Society, he states that the ferro-titanium alloy which contains no aluminum, or only very little, alloys with the steel with great difficulty. It appears that, in 1897, the Goldschmidt interests placed a 35 to 40 per cent. titanium alloy on the market, which, it is claimed, did not find a ready sale, nor was a similar low-percentage alloy a success commercially. The alloy containing one part Al to three to four parts Ti was finally evolved and is now one of the principal products of the Goldschmidt Thermit Company. Doctor Goldschmidt holds that the aluminum is a necessary constituent, and that it has a triple function, viz., first, the titanium alloys with the steel with greater readiness if aluminum is present; second, the titanic acid which is formed in the molten bath is difficult of fusion, as is alumina, also produced by the addition of aluminum to a bath, but when both are introduced together a titanate of aluminum is produced which is more readily fusible; third, the aluminum serves the purpose of deoxidizing the steel before the titanium is brought into action, and the titanium is not called upon to do the work of rough deoxidation which the aluminum is better able to do.

The Goldschmidt product has the following average analysis:

Silicon	1 to 1.5 per cent.
Titanium	25 per cent.
Carbon	*nil*
Manganese	*nil*
Aluminum	5 to 6 per cent.
Phosphorus	0.05 per cent.
Sulphur	0.01 per cent.
Iron (by difference)	balance

Cupro-titanium.—Cupro-titanium is manufactured by the Rossi process, and calls for the reduction of rutile in a bath of aluminum to which copper has been added for the purpose of alloying with the reduced titanium. The method is otherwise the same as the process for the production of ferro-carbon titanium. Of course, ilmenite cannot be used as a source of the titanium, as the product can contain no iron. Experiments are still in progress to improve and reduce the cost of producing cupro-titanium, and the alloy has not as yet been exploited in the commercial field to any degree.

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[57] "Titanium in Iron and Steel," *Trans. Amer. Electrochem. Soc.*, 1911, vol. xx, pp. 265–279.

Mangano-titanium.—This is a titanium alloy brought out by the Goldschmidt interests for use as a deoxidizer in bronze practice. The alloy contains from 30 to 35 per cent. titanium.

B. INCANDESCENT MEDIA.—One of the most important uses to which both metallic titanium and some of its compounds have been put is for incandescent media for illumination. Certain of the titanium compounds have been employed in the manufacture of arc-lamp electrodes, of filaments for incandescent lamp use, and of gas mantles. The worth of the metal, either elemental or in the form of some of its compounds, in this field, is directly due to their elevated fusion and vaporization temperatures and to their radiation efficiency. The General Electric Company, at its Schenectady works, carried on extensive experiments for a number of years with material for arc-lamp electrodes. The results,[58] which were withheld for commercial reasons for a number of years, showed that substances containing titanium gave the highest efficiency. In 1890 the first patent in the United States was procured, calling for the use of a titanium compound in arc-lamp electrodes, while prior to this date (1878) Thomas A. Edison secured an English patent for the use of titanic oxide for the same purpose. Rutile has been employed to a considerable extent in recent years in arc-lamp electrode work, and it is claimed that such electrodes are superior to carbon electrodes, particularly for street lighting. The one disadvantage is that they cannot be used on alternating-current systems. A patent was procured in 1907 [59] for an arc-light pencil consisting of a metallic titanium alloy, as ferro-titanium. The light is yellowish to white in appearance. Still more recently a large number of patents have been secured calling for the use of titanium carbide. Electrodes made of titanium carbide, either alone or admixed with other materials, have found some application, and a great deal of time and research has been expended with the work. These electrodes in action are comparatively free from the unpleaasnt hissing of the carbon electrodes, and they are further very steady and more durable.

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[58] Weedon, W. S., "The Titanium Arc," *Trans. Amer. Electrochem. Soc.*, 1909, vol. xvi, p. 217 *et seq.*

[59] U. S. Patent No. 840,634.

Besides the compounds already mentioned, titanium suboxide has been used in electrode manufacture. The question of titanium for use in arc-lamp electrodes has been treated most particularly by Weedon, Ladoff,[60] Little,[61] and Barrows.[62] Titanium has been employed in the filaments of incandescent lamps of late, but these filaments as yet have not found widespread application because of technical difficulties connected with the manufacture of the wires. There is considerable paucity of data on this particular subject because of the commercial aspect of the business, and it would not be surprising if the results were withheld for as long as those pertinent to the use of titanium in arc-lamp electrodes.

C. MORDANTS AND DYES.—For use in the dyeing industry, titanium was first exploited in England. In general, the *ous* salts of the metal are powerful mordants which produce brilliant and stable colors. The company first interested in the work produced titanium ammonium oxalate from rutile by a complex and costly process which defeated the object in view. A number of titanium salts have been tried, but titanium potassium oxalate ($TiOC_2O_4, K_2C_2O_4. H_2O$) is the only one used extensively in the dyeing and textile industries. The compounds of titanium which have been successful find application as mordants and dyes for wool, cotton, and mixed goods, as well as paper. Titanous chloride ($TiCl_3$), titanous sulphate ($Ti_2(SO_4)_3$), and a double sulphate of titanium and sodium ($Ti_2(SO_4)_3. Na_2SO_4. 5H_2O$) have been produced. The first two have found application in the textile industries and are manufactured on a large scale both in this country and on the continent of Europe. Salts of titanium have also been used in dyeing leather for shoes, and do not embrittle the leather as is the case with salts of iron.

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[60] Ladoff, Isador, "The Titanium Arc," *Jour. Ind. and Eng. Chem.*, 1909, vol. i, No. 10.

[61] Little, George M., "New Developments in Arc-lamp and High-efficiency Electrodes," *N. E. L. A.*, Washington meeting, 1907.

[62] Barrows, W. E., *Electrical Illuminating Engineering.*

D. REFRACTORY COLORING MATERIAL IN CERAMICS, ETC.—Rutile is employed in the porcelain industry to produce a fine yellow color, the shade of color imparted depending upon the amount used. Rutile, because of its relative cheapness, has therefore supplanted uranium compounds, which are too expensive for commercial use. The mineral also finds application in the manufacture of artificial teeth to produce the color desired for matching. In dental practice, when artificial teeth are to be mounted, the teeth adjoining are matched with standard-colored teeth. Rutile gives the desired shade and, in the paste from which the teeth are moulded, varies from 0.5 to 4 or 5 per cent.

E. MISCELLANEOUS USES.—Titanium compounds have some other limited uses not already mentioned, as follows: Rutile crystals have been used for gems in jewelry mountings. Titanium nitride has been proposed as a basis for nitrogen and fertilizer manufacture, but has not been employed commercially as yet. Titanium dioxide has found application as a protective paint for iron and steel, while the sesquioxide (Ti_2O_3) and its salt derivatives have been employed in textile work as reducing agents. Other uses are instanced in the technical press, but are of not sufficient note to record here.

6. TITANIUM IN THE METALLURGY OF STEEL.

General Statement.—The important question arises: Has titanium really any influence on the properties of steel? The question[63] has been invariably answered in the affirmative by authorities because of the incontrovertible evidence brought out by actual experiment and that gleaned from the probably trustworthy literature on the subject. For some reason or other, there unquestionably exists considerable skepticism. It is the purpose of the following paragraphs to collate the more authoritative thought regarding the matter in order to demonstrate that the addition of titanium to steel has an important influence on its properties, and that its use is to be recommended to steel makers who have any regard for the quality of their product.

Titanium in the form of one of its ferro-alloys is used rather widely at present, and its use tends to increase, although there has been some falling off in its employment for the treatment of

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[63] Fitzgerald, F. A. J., "Has Titanium Any Influence on the Properties of Steel?" *Met. and Chem. Eng.*, January, 1915, vol. 13, p. 28.

Bessemer-rail steel. As a final deoxidizer and denitrogenizer in the metallurgy of steel, it follows the usual treatment for these objects with ferro-manganese, or spiegeleisen, and ferro-silicon. Leading metallurgists seem to agree that titanium achieves its remarkable results through its strong deoxidizing powers, together with its effect of giving the slag sufficient fluidity to completely separate it from the metal. The presence of titanic oxide (TiO_2) lowers the fusion point of occluded slags in iron and steel and thereby imparts the fluidity which will account for their elimination.[64] The statement that occluded oxides and gases, such as ferric oxide (Fe_2O_3), ferrous oxide, (FeO), free oxygen and nitrogen, etc., are undoubtedly the real causes of many of the difficulties of steel makers needs scarcely be made. A great deal of data has been secured pertinent to the disastrous effects of sulphur and phosphorus; that the effect of the former has been overdrawn is demonstrated by the recent work of Unger[65] and Hayward.[66] In fact, many metallurgists have agreed for years that the harmful influence of sulphur was indeed mythical at times; *i.e.,* within certain limits. The fact, however, that both occluded oxygen and nitrogen in steel reduce its static strength and dynamic properties, and otherwise injure it, has been definitely shown. The feeling is that free oxygen and oxides are more harmful to steel than either phosphorus or sulphur within certain quite wide ranges. The investigations regarding the presence and effect of nitrogen are incomplete, and the results, therefore, are uncertain. The presence of nitrogen to the extent of 0.02 to 0.025 or 0.045 per cent. in certain steels is enough to cause them to break asunder, destroying all elongation and reduction of area.[67] Some experiments made in the research laboratory of a mid-western steel plant[68] showed that certain large percentages of nitrogen could be readily incorporated into ingot iron, and that there occurred a resultant great brittleness of the metal; in fact, in some cases the iron could be pulverized in the fingers.

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[64] Stoughton, B., U. S. Pat. Office, Proc. Ser. No. 463,610.

[65] Unger, J. S., "High and Low Sulphur in Basic Steel," *Iron Age,* January 13, 1916, p. 146.

[66] Hayward, C. R., "The Effect of Sulphur on Low-carbon Steel," *Bull. A. I. M. E.,* October, 1916, p. 1841 *et seq.*

[67] Le Chatelier, H., Paper, Congress of Metallurgists, Belgium, 1905.

[68] Private communication, June, 1916.

The great affinity of oxygen and titanium is an absolutely sure method for completely deoxidizing a steel, the advantages of which need no elaboration. It has been proved that an ingot of steel containing a very little titanium will be practically free from segregation.[69] Bessemerized and Tropenas-converted steels are known to contain the greatest percentage of occluded oxides and gases, with open-hearth, crucible, and electric-furnace steels following in the order named. The reason for this lies in the mode of manufacture. Titanium has a strong chemical affinity for oxygen and will remove traces of it from the metal, which otherwise do not yield to the ordinary deoxidizers with their concomitant carburizing reactions. Its apparently unique property of removing occluded oxidized substances by causing them to separate more readily avoids the most harmful effects common to steel products. Titanium, in removing nitrogen, is one of the very few elements which attacks this relatively inert gas. The fact that titanium tends to lessen segregation of steel ingots may well be believed because of the well-known influence in this respect of agents which deoxidize and thus quiet a wild metal.[70]

Until recent years titanium was regarded as a rare metal; its use, although it was known to be one of the most potent of deoxidizers and denitrogenizers, was prohibited, by reason of high cost, until the exploitation of the ferro-alloys. These alloys, as already stated, are produced by two different methods: first, the electric-furnace process of A. J. Rossi; and, second, the aluminothermic process of Dr. Hans Goldschmidt. The function of the alloys made by both processes is the same. Titanium appears to exert little direct effect on the constitution or structure of the steel itself. Although it lowers the Ar_3 point, it has little influence on either Ar_2 or Ar_1, and steels with as much as 10 per cent. Ti exhibit the normal pearlitic structure of straight carbon steels. Besides its use as a superpurifier for rail steel, titanium is finding application in the treatment of steel and iron rolls where resistance to abrasion and shock is thereby said to be increased; for steel castings in foundry practice; for both low and high carbon steel chain; for gears, pinions, tires, die plates and heads, propeller shafts, driving rods and other forgings; for tool and automobile steels; for cast-iron ingot moulds; for acid pots, and chilled-iron car wheels. It is also said to improve the qualities of nickel and chromium alloy steels, as well as manganese steel. The use of titanium in small quantities in manganese steel, in particular, promises to give results of great value. Manganese steel containing 11 per cent. Mn, one per cent. C, and a small amount of titanium—up to 0.40 per cent.—is readily forged and rolled and can be machined with comparative ease. Such steel is extremely hard, and yet very strong and tough, having a tensile strength of from 65 to 70 tons per square inch and an elongation of 45 per cent. on a 2-inch length.

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[69] Von Maltitz, E., *Stahl und Eisen*, No. 41, 1909.

[70] Waterhouse, George B., *Proc. A. S. T. M.*, 1910, vol. x, pp. 201–211.

How Titanium is Used in Steel Metallurgy.—The modern method of employing titanium as a final deoxidizer and denitrogenizer is to augment the incomplete cycle, after the other deoxidizers have been added, by using one of the ferro-titanium alloys. The other deoxidizers may be added either in the furnace or in the ladle, but it is best that the titanium alloy be added in the ladle, and, further, that time be given for the titanium to complete its clarifying action. Thus the ladle will be held for five to ten minutes before pouring, so that the entrained slag formed may have time to rise to the surface. There is no opportunity for the bath to chill by thus holding it, because the titanium action is exothermic, the temperature of the metal being appreciably raised. Titanium, by combining with oxygen with the production of titanic oxide (TiO_2), has a heat of formation of 218,000 calories. The cost of treatment of steel with ferro-carbon-titanium (the Rossi product) varies from about 25 cents to $2 per ton of metal treated. It is the cheapest deoxidizer above the grade of ferro-manganese or ferro-silicon. At the prices which ferro-manganese has reached in the past year (*i.e.,* from $200 to $450 per ton, tidewater) it is a cheaper deoxidizer, when it is considered that American steel makers use about 19 pounds of the manganese alloy per ton of steel produced. The amount of the titanium alloy to be added is normally very small and should be proportioned according to the amount of impurities present.

A broad dictum says, "Make the steel in the furnace." The deoxidation of the steel is best performed in the ladle. Regarding the addition of the titanium alloys, these are best added to the ladle of steel after tapping from the furnace and before the slag has begun to run. For open-hearth steel, the supply of alloy is placed at a convenient spot and, at the proper time, shovelled in. For soft mild steel, an addition equivalent to about 0.03 per cent. of titanium is enough to do the work required, under normal conditions. In general, larger amounts effect increased benefits, but, in the case of the carbon-bearing titanium alloy, they cannot be added because of the introduction of too much carbon thereby, and also because of the density imparted to the steel, which increases in proportion to the alloy addition and consequently is not always desirable. In the case of high-carbon steels, the increased density is more often desired and larger amounts of the alloy can be used.

In Lackawanna practice in making open-hearth steel, ferro-manganese and ferro-silicon are added to the ladle, as is normal practice in the United States. These alloys are added as soon as the ladle bottom is covered with hot metal from the tap, and the titanium-alloy addition follows as soon as possible. As already mentioned in the preceding paragraph, the titanium addition is to be made before the slag begins to run, otherwise it is difficult for the alloy to get down through the slag covering on top of the bath. The same thing is true for ferro-manganese and ferro-silicon also—the essential requisite is to incorporate the alloys with the steel and not with the slag. Further, the titanium alloy must not only be thoroughly incorporated with the metal bath, but it is highly important that sufficient time be allowed for the chemical changes to take place. The oxides that are formed, and the different gases or compounds, or whatever they may be, must be given time to separate from the steel and rise into the slag. What has just been said for open-hearth practice applies in general to Bessemer-converting practice. In the latter, the spiegeleisen and ferro-manganese are added to the converter; then, as the steel is being poured into the ladle, the titanium alloy is added; the ladle is then held for a few minutes before teeming the steel into ingots.

In Bessemer Practice.—In the Bessemer process the titanium alloy should be shovelled into the stream of metal which is being poured into the ladle, the steel having been recarburized in the converter prior to pouring, as is normal procedure. Inasmuch as the titanium reacts vigorously with molten silicate slags, it is strongly recommended that it receive the maximum amount of stirring with the metal before much of the slag begins to run.

otherwise much of it will be wasted. In order to effect a churning and stirring of the metal so that the titanium alloy is thoroughly incorporated, it appears expedient to allow the molten stream to strike the ladle a little off centre, so that the bath receive a gyratory stir. After the alloy is properly mixed, it is best to hold the ladle for about three to five minutes so that the titanium may have time to complete its action and remove most of the dissolved oxygen, nitrogen, and entrained oxides and slag. The titanium alloy screened through a 0.125-inch screen and packed in convenient sized cans is recommended for Bessemer practice or for Tropenas converting.

(*To be continued*)

The Utilization of Pyrite Occurring in Illinois Bituminous Coal. E. A. HOLBROOK. (*University of Illinois Bulletin,* vol. xiv, No. 51, August 20, 1917.)—The mineral pyrite (or probably its name is marcasite) occurs in nearly all Illinois coals as characteristic brassy yellow colored streaks, thin plates, lenses, nodules, bands, or balls of all sizes, sometimes up to 10 or 12 inches in thickness. In the ordinary course of mining, pyrite is rejected as a deleterious impurity. When pure, pyrite contains more than 50 per cent. of sulphur, and when the nearly pure mineral is properly burned or roasted, the sulphur dioxide gas resulting forms the basis for the manufacture of sulphuric acid. In normal times the commercial supply of sulphuric acid is obtained as a by-product of the roasting and refining of zinc, lead, or copper ores, which contain sulphur. The prohibition against undue atmospheric pollution in the neighborhood of smelters, due to the formation of sulphur dioxide, has often made its recovery a matter of necessity not regulated entirely by market demands for the resulting sulphuric acid.

In normal times in the United States the market for pyrite has been irregular and has been limited to small areas near the points of production and utilization, owing to the fact that high freight rates have operated against extensive distribution. Moreover, Spanish pyrite has normally been imported easily and cheaply to the extent of a million tons or more per year, usually in vessels which would otherwise return to America in ballast. Since the beginning of the European war the supply of Spanish pyrite has been largely cut off, and under present market conditions (July, 1917) a clean pyrite product is worth three or four times as much per ton as the coal with which it occurs. A series of experiments conducted on a commercial scale has shown that, where pyrite occurs in sufficient quantities to justify its recovery, a 50-ton plant may be designed to serve a single mine or group of mines which will yield a profit of about $75 per day, or $1.50 per ton of raw pyrite, with an initial capital cost of about $18,000. The market for domestic pyrite is active and prices as high as $8 per ton are offered.

DEVELOPMENT AND PROGRESS IN AVIATION ENGINES.*

BY

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The art of aviation and the industry of building airplanes, engines, and accessories, to meet the demands of the art, are now going forward with wonderful strides. Commercial usage as well as war usage begins to attract the attention of the aeronautic engineer.

It is interesting to refer back a few years to the Journal of The Franklin Institute, dated October, 1910, and learn to appreciate the rapidity of change in the art. Reference is made therein to a "useful load of 450 pounds, including three passengers." This weight is the equivalent of about 75 gallons of gasoline, which is less than the amount required for four hours' flight of a two-passenger airplane of recent design and construction. Nearly twice this volume of gasoline is now carried, with two passengers and 150 pounds additional useful load.

Reference is made to airplane flying altitude: "Prominent aviators who undertake a cross-country flight select their course with care and maintain a very high altitude." "Lambert, who ordinarily does not seek high altitudes, in soaring over Paris, was obliged to ascend to a height of more than 1600 feet." In the war zone danger is now imminent below 16,000 feet altitude. Much flying is necessary at greater altitudes. Peaceful cross-country flying is done at what are now called safe altitudes of from 3000 to 7000 feet. From such altitudes it is probable that a suitable landing area could be reached in case of need. With a "dead" engine the angle of glide is about six to one. This means that a six miles radius circle is available for a choice of landing from an altitude of one mile.

Duration of flight is referred to as follows: "Present-day flights are no longer measured in minutes." "The hour has been exceeded by many pilots." "The aëroplane will enter the field of touring." All this and more is now true after a period of six years.

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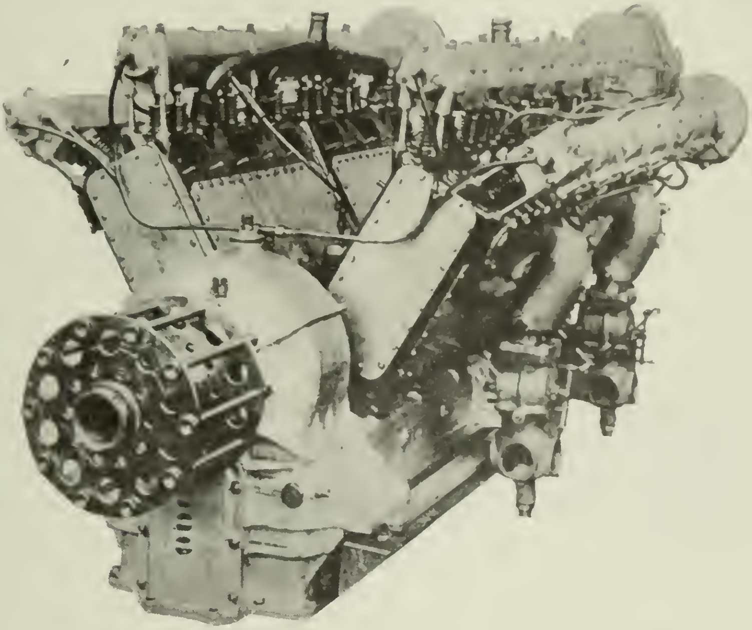
*Presented at a meeting of the Mechanical and Engineering Section, held Thursday, March 1, 1917.

Aviation engine weight per horsepower delivered has not changed much; but engines are more reliable, more efficient and stronger, and heavier where experience has taught the need. The term "weight per horsepower" is a loose one. There are many parts that may or may not be considered as a part of the engine of the power plants to be included in the weight. Some twenty-eight or thirty items have been found in this doubtful class. The weight of gasoline and oil consumed per hour is figured by some as an element of engine weight. It does influence the design of the airplane as a whole. It must be known. For example, the rotary, air-cooled engine, although very light, about two pounds per horsepower, is outclassed by heavier engines if the airplane must fly more than three hours. The rotary engine consumes too much gasoline and oil per horsepower-hour for long flight.

Reconnaissance airplane and pilot (Carlstrom) that made Chicago-New York flight. (Curtiss Model JN4.)

Broadly speaking, it may be said that the weight may safely vary from two to five pounds per horsepower. This will include the weight of magneto, carburetor, and wiring. Other elements of the power plant, such as water, water piping, oil in the engine and the propeller, are not included.

An engine which ranks very high for speed, climbing, and endurance weighs 2.4 pounds per horsepower. This engine is high strung and delicate, but very effective. Many types of engines are in practical use. There is an ever-changing idea as to the proper function for each type, and a constant shifting of opinion of one engine to another of any given type, as to the superiority. Any improvement of design, material, or workmanship may result in temporary superiority. Competition in this matter is keen. All sorts of daring expedients are tried under war pressure. The result is rapid change and rapid improvement.



Sterling-Sunbeam 300-horsepower engine, 12-cylinder, V type.

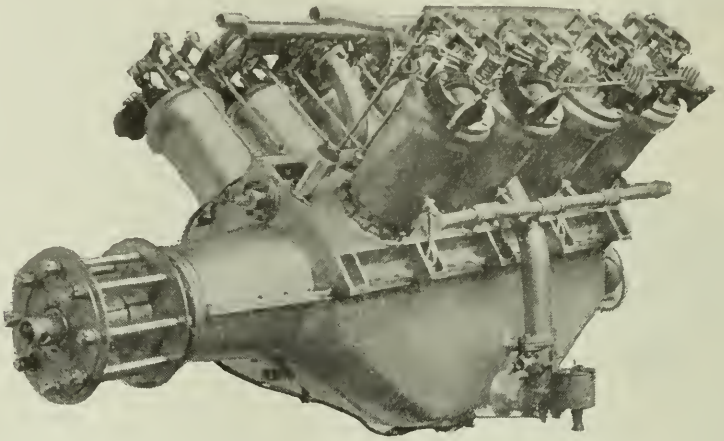
The future one may not predict. The probable status six months hence is only speculation. It is certain that greater horsepowers are appearing for all types and sizes of airplanes. The result is increased speed, climb, and load-carrying capacity. There seems to be no limit to this increase except that imposed by lack of experience. This lack is being made good very rapidly just now by war conditions.

About a year ago it was thought that no more than 90 horsepower could be obtained from a radial rotary, air-cooled engine. One-third more has been obtained, and nearly double is now planned.

Similar improvement is being brought about, by experience, in other engines. An eight-cylinder, V-type engine now develops consistently 210 horsepower. Six months ago it did not function as consistently at 180 horsepower. There has been no radical change of design or size.

Experience has been the teacher. No internal-combustion engine of new and extreme design can be brought to a condition of practical excellence in less than a year, and often two years. Yet partially developed engines must be purchased and used or there will never be complete development.

The next, and very important, step is the development of organizations that can really manufacture an aviation engine or airplane, rather than build a few models, or a dozen or two nearly alike. This is a task that will easily occupy another year of consistent endeavor. At least one aviation manufacturing organization finds itself in this state of development. The building nucleus of men must be expanded into a manufacturing force. The product must be adapted to practical methods of manufacture, to existing tools, and standards, so far as possible. Otherwise no quantity production may be expected.

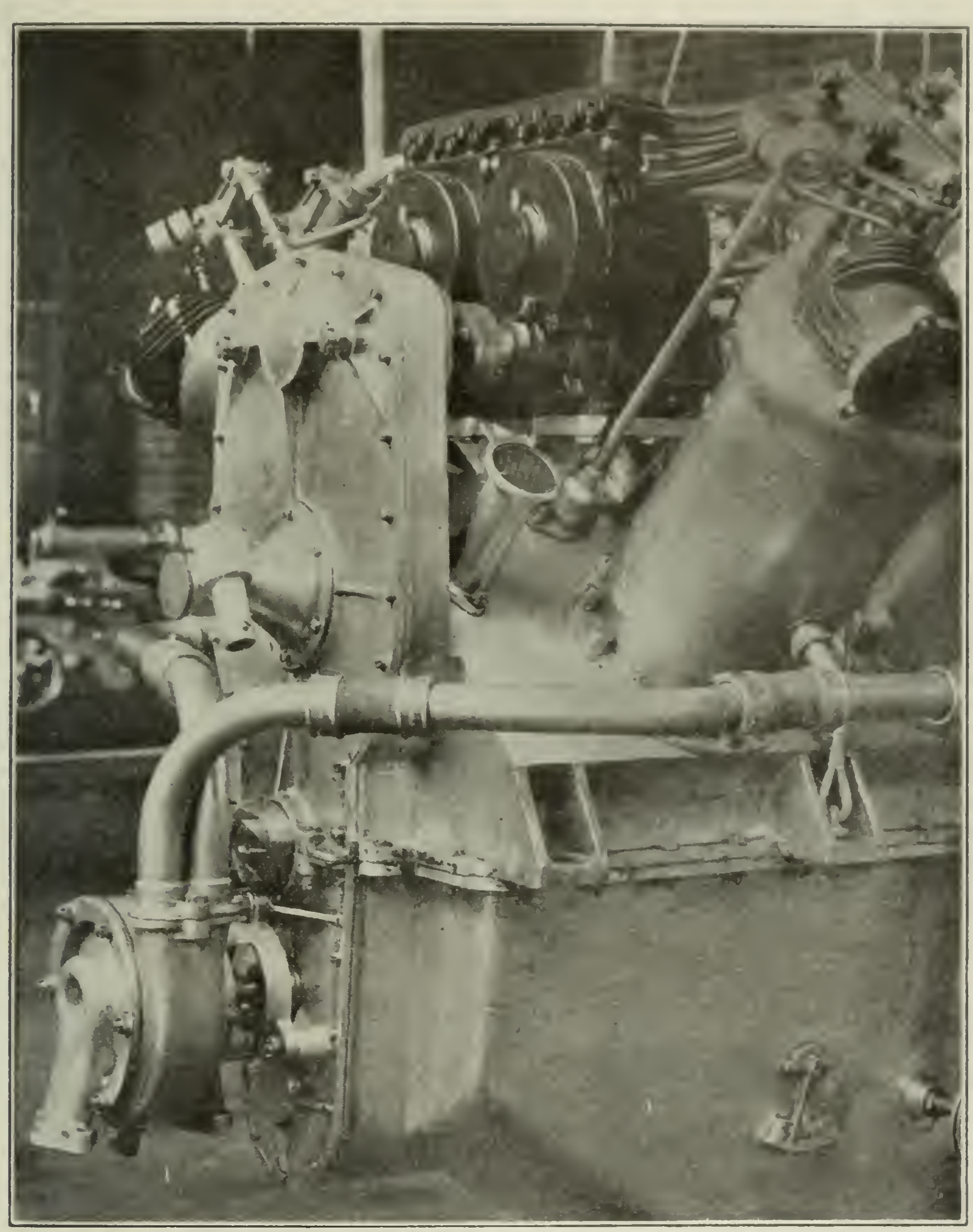


Curtiss V2, type 3, 200-horsepower engine, 8-cylinder, V type. Front end.

This has been proved many times in other industries. The aircraft industry is not different. In fact, it is astonishingly similar to the motor-car industry as found during its beginning and early growth.

Perfection would be approached by having each plant producing aviation material, as engines or airplanes, so organized and equipped as to manufacture one type only and do that well.

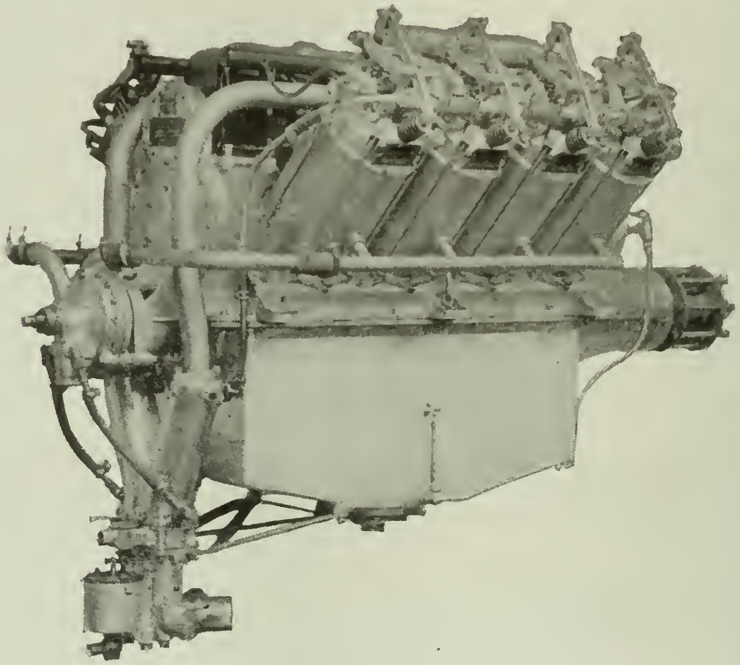
This condition will be brought about by a consistent demand or in response to a pressing need. A proper foundation for such a development is now being laid by the same engineering body that assisted in the amazing growth of the motor-car industry—The Society of Automotive Engineers (recently Automobile, but expanded to include closely-allied industries, of which aviation is one). Its standards and engineering practices will creep into the new industry as they did into the older one.



Curtiss V2, type 3, 200-horsepower engine, 8-cylinder, V type. Rear end.

It is difficult to discuss aviation without mentioning the Wright Brothers. They developed much knowledge of flying without an engine by gliding experiments, and then sought an engine.

At the outset of the automobile industry the power estimated as necessary was too small. Practical tests indicated that three horsepower would suffice, with a generous factor of safety. History repeated itself. Orville Wright recently stated that an eight-horsepower engine was figured as necessary. Such an engine, not to exceed 200 pounds in weight, was sought in the open market. This occurred in 1903, and none was offered that was worth considering.

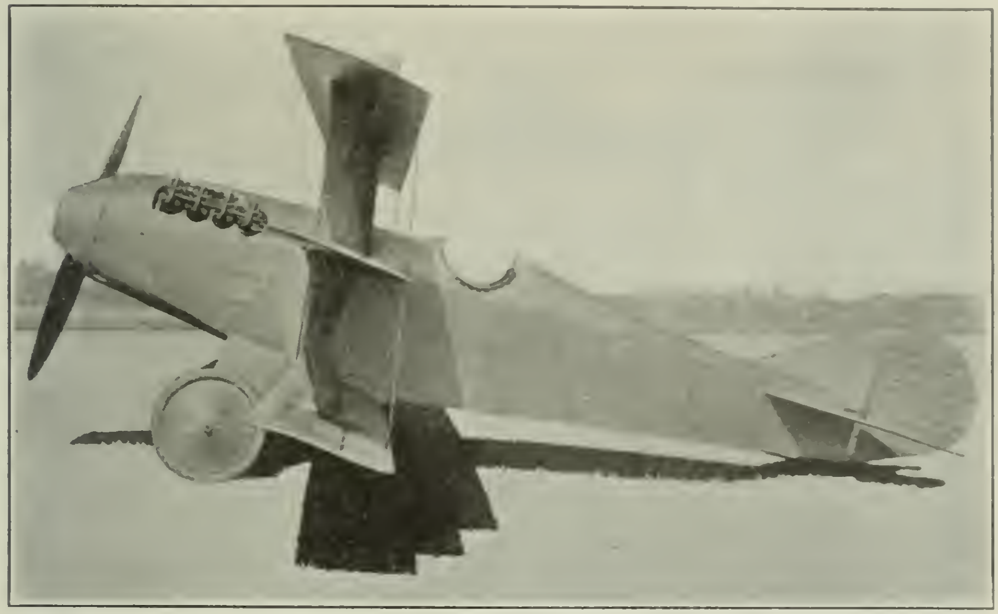


Curtiss OX 100-horsepower engine, 8-cylinder, V type. Rear end.

The Wrights then built a four-cylinder 4 x 4-inch engine that did weigh less than 200 pounds. This engine developed 12 horsepower and actually flew an airplane. This engine was followed soon by a much better one that developed 30 to 35 horsepower. It was simple in the extreme degree. A jet nozzle in the intake pipe served to atomize the gasoline; the ignition was a low-tension system; the water jackets were of sheet aluminum, the crank shaft very small in diameter, as were all other moving parts. Later engines of the same design have produced more power, are very efficient, and still being used to a limited extent.

The four-cylinder vertical engine was the first aviation engine to do real service. The airplane flown with so small an amount of power was large in wing area for the load carried, slow in speed, and sluggish in movement, judged by present standards. Such an airplane resembles the butterfly rather than the swallow. It is not like the successful fighting machine, yet will surely find place for peace usages.

Closely following this first type of engine came six-cylinder vertical and eight-cylinder V engines of 65 horsepower and 75 horsepower. All of these were too light and frail for hard service. Minutes of flight were possible, but not hours, as now required. High-pressure lubrication to vital parts had not been developed. Valves failed because of inadequate cooling and material.



Curtiss model S3 triplane speed Scout.

In August, 1908, the Wright Brothers made their first flight in France. Following this date, the French engineers developed airplanes and engines of various types that embodied the fundamentals demonstrated by the Wrights, so far as the airplane was concerned. The scientist contributed much to the art by working out the theory of the art of flying. A long step forward was taken in the succeeding years.

Air-cooled engines of the radial rotating form were developed, then air-cooled and water-cooled vertical and fixed cylinders These successive steps again repeated the steps taken by those who had developed the automobile and its engine: all were too frail and of small power. It seems safe to state that nothing as large as 100 horsepower was reached or thought necessary. The Gnome radial rotating engine became most successful, and, as experience improved the skill of the aviator, the power of the engine grew gradually from 60 horsepower up to 90 horsepower.

Comparison between reconnaissance biplane (Curtiss model JN4) and triplane scout (Curtiss model S3).

Similarly the speed of the airplane increased up to 60 or 70 miles per hour, with slow speed or landing speed in the neighborhood of 40 miles per hour.

After a few years of this normal development, with reasonable progress relatively slow because of the enormous cost attending aircraft experiment, came the present European war. Then began a feverish and rapid development, during which rash moves were made and long chances of an engineering character were taken. How much the demands of war have advanced the art of aviation can only be guessed, but surely as much as a generation.

As soon as the absolute necessity of aircraft as a part of a modern army was demonstrated, the production of them was forced to the limit.

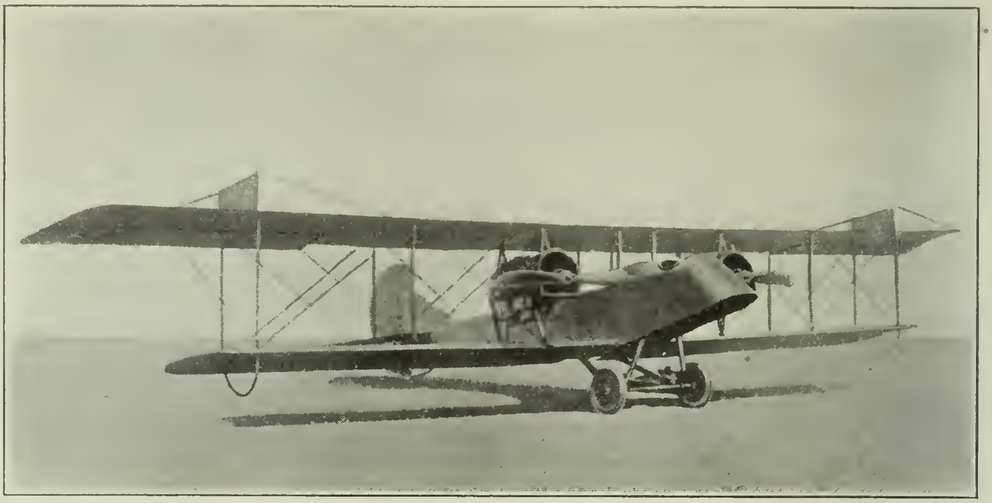
Extreme types are built and flown. Planes of small area, equipped with engines of large horsepower, which must be landed at 80 miles per hour, must be used. This type is the fighting craft that seeks altitudes above the hostile projectile danger zone (about 18,000 feet), and higher yet in order to be able to swoop down on the slower plane or upon some less skilful aviator. One hundred horsepower is no longer enough for this light and agile airplane. An engine, eight-cylinder, V type, of 150 horsepower, is most popular now, but with a tendency toward, and small actual use of, 200 horsepower, yielding a speed of 140 miles per hour and a climb of more than 1000 feet per minute.

Curtiss model JN4P military tractor.

The only type of airplane used for war purposes, satisfied by an engine of 100 horsepower or less, is the school machine, which carries teacher and student, tandem or side by side, in the body. Thousands of these are needed and being used in Europe. It is pleasing to know that one engine being built in the United States is giving excellent satisfaction in England for this purpose.

For large warcraft, battleplanes so-called, more powerful engines are used. So far as known, this demand is met by engines of 250 to 350 horsepower. These aircraft carry bombs or explosives up to 1000 pounds in weight, and small defensive guns. They are not agile nor fast, and are defended by fast machines, when possible to do so. They are the battleships of the air, defended by the torpedo-boat.

To produce this power, 12 and 18 cylinders are used. The latter is of the V type, with three rows of cylinders in place of two. It is new and said to be very successful. The power is transmitted to the propeller through gears, the propeller rotating about three-fifths engine speed, at about 1000 to 1200 revolutions per minute. Wherever possible, gearing is avoided because of the great weight added and increased mechanical difficulties. The difficulties surrounding the propeller problem also deter. The combination of much power and high speed tends to wreck propellers. There are many elements entering into this phase of the use of large powers not yet fully understood.

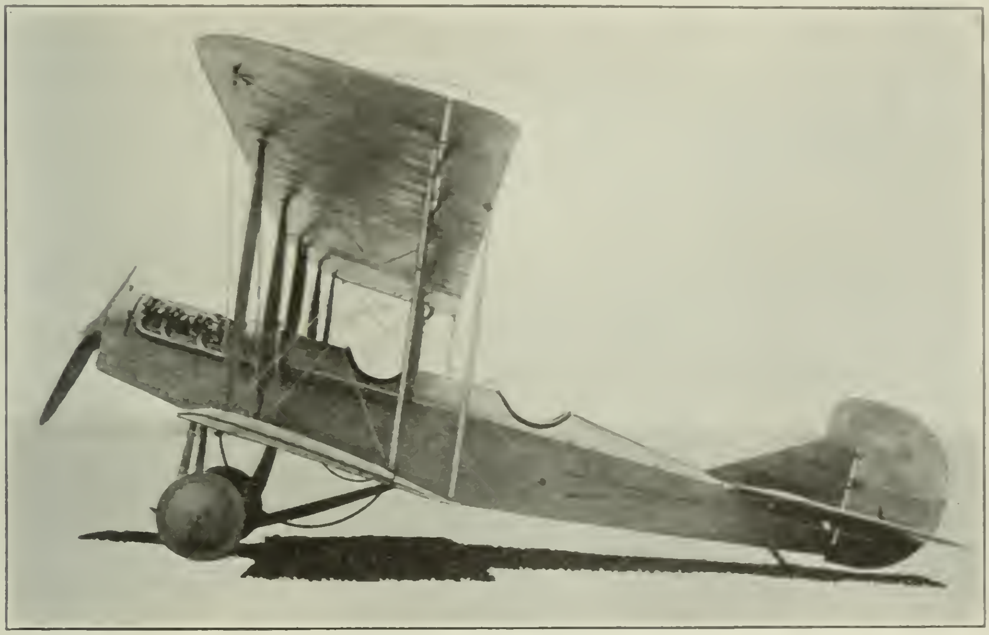


Curtiss model twin JN military tractor.

An obvious means to equip an airplane with more power is to use more than one engine unit. This is done and will be done, but there is a penalty attached to the plan. The ideal disposition of weight in an airplane is to have all concentrated at the centre of gravity of the entire structure. A single engine unit approaches this condition as nearly as may be. Two units mounted out in the wings, away from the centre of gravity, increase the inertia, decrease the agility and manœuvring quality very much. An airplane so equipped cannot quickly turn and twist to avoid the attack of the fast machine.

There will come a time when all engineering attention is not drawn to airplanes for war purposes. Then a type of plane will be developed that will not have speed, agility, and climbing power as its principal attributes. Much less power will fill this need, and a much more normal aircraft will result. Then the multiple-unit plane will have a chance to develop.

Our present aircraft development is what the racing car has been to the automobile industry—a wonderful developer for normal product and usage. In time real manufacture will begin, prices will drop and popularity increase. Engines to meet such a purpose will develop rapidly. They will, as now, be highly refined as to their essential functions, but of ordinary construction as to the non-vital functions. At present the extreme of design, workmanship, and material is the aim for all parts. The art is too young to permit any other procedure.



Curtiss model R4 military tractor.

ENGINE DESIGN.

The desired engine must be light but it must be reliable. It must be capable of continuous operation at very nearly full capacity for long periods. A 20,000-foot climb requires that everything shall be perfect.

The periods of partial use and rest are short, as for a glide. The period of level flying is from 75 per cent. full power to full power, at the desire of the operator. Pursuit or flight means full power, patrol or observation duty means less; but at no time does the usage approach that of the motor-car engine. The demand is even greater than that on the marine engine, which carries a very constant load; but the marine engine may be made heavy—the aviation engine must be light.

Experience has taught that lightness must be abandoned in favor of stiffness and strength for all vital parts, such as crankshaft, crank-base, main bearings, crank-pin and piston-pin bearings, and that all possible lightness must be gained by hollow construction in combination with materials most carefully chosen. Coupled with these features must be found most thorough oiling at high pressure, with oil led in a positive manner to all vital points. Much experimenting must be done, even after careful design, to arrive at a proper distribution of oil. Clearances, oil apertures and oil viscosity (hot) must be balanced.

Curtiss model twin JN seaplane.

Poppet valves must close on seats that are thoroughly cooled. Exhaust valves run cherry red hot at best. Proportions and detail of design must avoid warping and breakage.

Ignition is desired in complete duplicate for each cylinder. Magnetos must be coupled and driven in such a manner as to minimize vibration. Magneto difficulties have been of mechanical failure more than electrical, and the direct result of excessive strains due to rigid driving couplings. Wiring must be carefully conducted and fastened to prevent failure from chafing, following excessive vibration.

Spark-plugs have been the cause of more trouble and uncertainty than any other single item of aviation engine detail. The prime difficulty has been to keep the plug cool. A cool location must be provided in the design. The plug must not extend so far into the explosion chamber as to be seriously flame-swept, nor must it be deep in a hole or recess with delayed and irregular ignition. The plug itself must be gas-tight to prevent "blow by" and resulting overheat. The plug that satisfies the automobile engine will fail quickly under aviation service. This defect is more serious than appreciated, and must be guarded against. It is not easy to locate, as often assumed. Frequent change of plugs is now resorted to in the interest of reliability. Close attention to the foregoing and simple items will surely increase spark-plug life and engine reliability.

Curtiss model N9 seaplane.

There is no more mystery about an aviation engine than about any other, when the real truth is known.

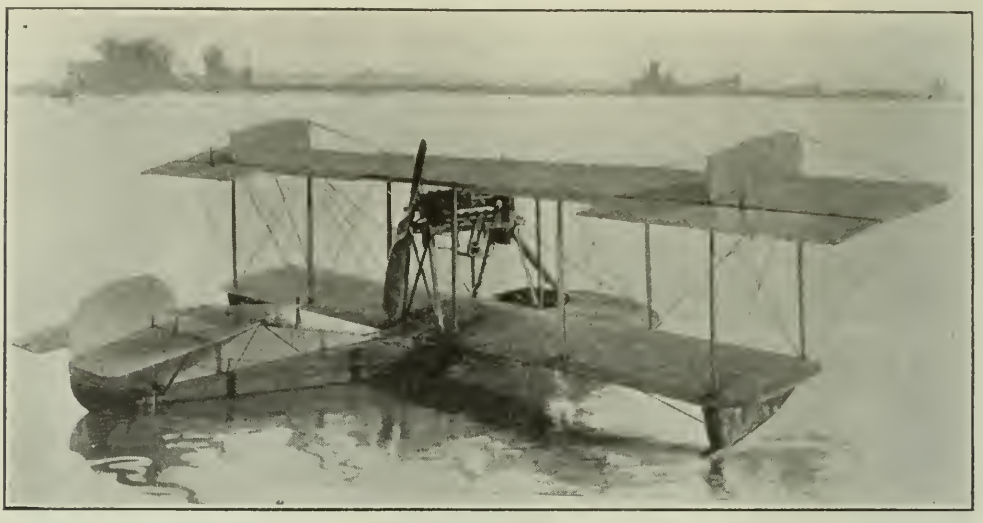
One hundred and fifteen pounds per square inch mean effective pressure is very hard to handle in connection with a light bit of construction. This pressure is needed to yield the horsepower per unit volume.

The perfect balance of moving parts is necessary. The airplane structure is very sensitive to vibration, and the occupants are seriously disturbed by an engine not functioning smoothly.

Perfect distribution of gas to give uniform explosions is a requisite. The delicate engine structure fails rapidly under the influence of irregular impulses. Carburetor parts, thin aluminum castings, wiring, gasoline tanks and piping, magneto, radiator, and propellers all fail to a serious extent in the presence of vibration.

Simplicity of design, with the smallest possible number of parts, must be the aim. Each additional screw, joint, part, or accessory increases chance of trouble in the air. The failure of such detail may cause a forced landing accident—as surely as the failure of a vital part.

The fire risk may be minimized by such design of engine compartment as will promote the movement of a large volume of air in and out of the engine compartment—in such a way as to carry gasoline or gas clear of the airplane body and operator's cockpit. Without an accumulation of gasoline the danger is small.



Curtiss model F flying boat.

ENGINE WORKMANSHIP.

The keynote of this feature is that quality must come first, cost second or last. Time must be taken to arrive at the desired accuracy or finish. Time and money must be spent to balance reciprocating parts. A limit of one per cent. difference of weight for all pistons and rods in an engine is required in some cases. Exact balance of all pairs is required.

Piston rings must be tight as the result of perfect fit and bearing. Many rings must be discarded to get perfect sets.

Rings good enough for motor-car engines will not do the work in aviation engines.

The engine must not throw oil from any joint, valve stem, gear-box, or pipe. Oil so thrown may easily cloud the goggles of the pilot. Only the closest of fits will achieve such oil-tightness.

Castings, whether aluminum or iron, must be true and of even wall thickness and of extreme lightness. Many rejections must be made to get the uniformity needed. Such rejections should be figured by those accepting engine casting orders. The best of pattern equipment and forging dies must be furnished for a comparatively small number of pieces. This adds materially to the cost of a part, but is necessary to attain workmanship of aviation engine quality.

Curtiss Aeroplane Company—Assembly floor, showing large flying boat.

Machine tools, fixtures, and methods must be such as to produce absolute accuracy, regardless of cost. "Quality first" should be the watchword in aviation, not "Safety first," because high quality means safety.

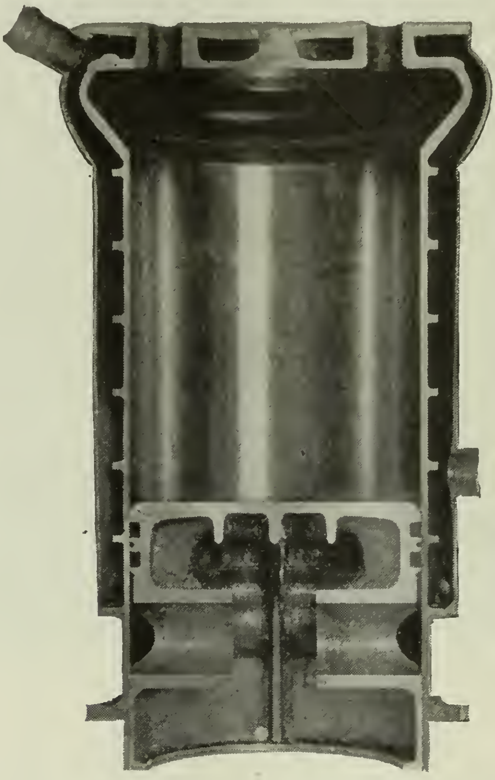
It is very hard to create this atmosphere among business men, superintendents, foremen, and workmen, who have always been obliged to keep in mind the cost and selling price of a product to meet competition. There is no competition in airplane engines yet. The art is too new. Performance comes first. Only the best in design, material, and workmanship will suffice.

It is possible that too much time and money are being spent; but at this time experience has not been great enough to be certain of this. Continued use over a long period of time will determine. During the youth of the industry is not the time to take a chance.

Quality and safety come first.

ENGINE MATERIALS.

Excellent material is required for a motor-car engine, which is rarely worked to anywhere near its limit of power. Take for an example a 40-horsepower engine. It runs quietly about over roads nearly level, with liberal lubricant for the work being done and consuming hardly 25 per cent. (10 horsepower) of its rated power.



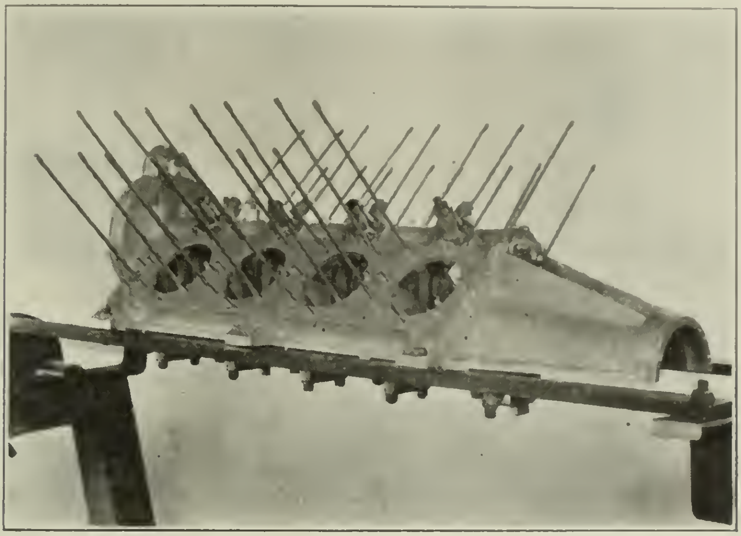
Cross-section of steel cylinder and aluminum piston, Curtiss V2, type 3, 200-horsepower engine.

Under comparable conditions an airplane engine uses 75 per cent. of its power. Lubrication must be perfect, not nearly so.

Further: a motor-car engine of 672 cubic inches capacity is given a normal rating of 65 horsepower. An aviation engine of the same volume is rated at 154 horsepower. As a motor-car engine not over 25 per cent., or 16 horsepower, would be ordinarily used, but as an aviation engine not less than 75 per cent., or 114 horsepower, would be habitually used, a ratio of about 7 to 1.

In addition, the aviation engine is built as light as possible, say about one-half the weight for a given piston displacement. Roughly speaking, this represents a punishment of material within the aviation engine 14 times as severe as that in the motor-car engine.

The present life of an aviation engine indicates severe punishment. Up to the time when a complete overhaul is necessary this life is about 50 hours at, say, 100 miles per hour, or a total of 5000 miles. A motor-car engine runs about 25,000 miles up to the time when an overhaul repair is necessary. The speed cannot average over 25 miles per hour. This means 1000 hours' operation, or 20 times that of the aviation engine.



Upper half of crank-case for Curtiss OX 100-horsepower engine.

A severe test of endurance for the motor-car engine under shop or laboratory conditions, and where destruction of the engine is invited and closely approached, is under a development of power of about 0.15 horsepower per cubic inch displacement. It is considered a fine performance for a stock motor-car engine to last 300 hours under this load. The aviation engine must do not less than this at any time and with 100 per cent. score. Otherwise the engine is not a successful aviation engine.

These are rough comparisons, but they show the relative severity of work. To meet these severe conditions the very best of steel for each engine part must be used. "Best" means that money must not hinder, but high-priced steel is not sure to be best. The highest of technical skill must be utilized: first, to select the steel from chemical and physical soundness standpoints; second, to treat it in such a manner as to give the best possible endurance and the highest elastic limit consistent with the possibility of machining. Here, again, money must not be a consideration. Slow methods may be necessary to work the material.

The crank-shaft of a motor-car engine is usually so large and heavy as to permit the use of steel having an elastic limit of about 70,000 pounds per square inch and with a physical structure not very highly refined by heat treatment. Experience has shown this to be good practice.

The crank-shaft of an airplane engine may be more in diameter, but hollow to such an extent as to demand the highest elastic limit that can be machined, say from 120,000 to 140,000 pounds per square inch, with a reduction of area, denoting the highest refinement of grain, of 50 per cent. or more.

The lighter parts of a motor-car engine, such as valve rocker arms, are given a toughening treatment for a fair forging steel, say 60,000 to 80,000 pounds per square inch elastic limit. The rocker arms of an airplane engine are so light and delicate as to require a fine alloy steel most carefully treated to give resistance to vibration and alternate stress. The elastic limit should also be in the neighborhood of 130,000 pounds per square inch. This, coupled with hardness at certain points, brings additional care and expense.

The highest intelligence and widest experience are needed to arrive at the proper combination of hardness and toughness and endurance. Experimental work to the point of actual failure is necessary to arrive at the extreme limit of endurance. In the aviation engine the extreme is sought.

A decade hence there will exist an accumulation of empirical knowledge. Extremes will then be less common or else the extreme of to-day will be the commonplace of the future. Experience will repeat in aviation as in many other industries and arts.

(Illustrations for this article were obtained through the courtesy of The Curtiss Aeroplane Company and Sterling Engine Company.)

PHYSICS OF THE AIR.*

BY

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Professor of Meteorological Physics, United States Weather Bureau

CHAPTER VII.

ATMOSPHERIC CIRCULATION.

INTRODUCTION.

ATMOSPHERIC circulation, whether manifesting itself in a monsoon, for instance, or in only a gentle lake breeze, is a gravitational phenomenon induced and maintained by temperature differences. This can be well illustrated by the flow of water between two adjacent tanks when connected by an upper and a lower pipe and kept at different temperatures.

Let the two tanks, *A* and *B*, Fig. 25, be filled to the same level slightly above the upper pipe *u*, and let them have the same temperature. Under these conditions there will be no flow of water from either tank to the other. Now let the pipes be closed and let the water in tank *A* be equally warmed throughout. It will expand, providing its original temperature was not below 4° C., and the amount of water above each level in *A*, at and below the initial surface, be increased in proportion to its distance from the bottom. Hence the pressure due to gravity is everywhere throughout the original volume correspondingly increased—the maximum increase being at the level of the initial surface. If the lower pipe *l* be now opened, there still will be no flow of water from either tank to the other. But if the upper pipe be opened, water will flow from *A* to *B*, and in so doing will decrease the pressure on all parts of *A* and increase it on all parts of *B*. If *l* is also open, water will flow from *B* to *A*. If both pipes are left open and the water in *A* kept constantly warmer than the water in *B*, there will be continuous circulation of the water from *A* to *B* through the upper pipe and from *B* to *A* through the lower. Obviously the same results could be obtained by applying a cooling process to *B* instead of a warming one to

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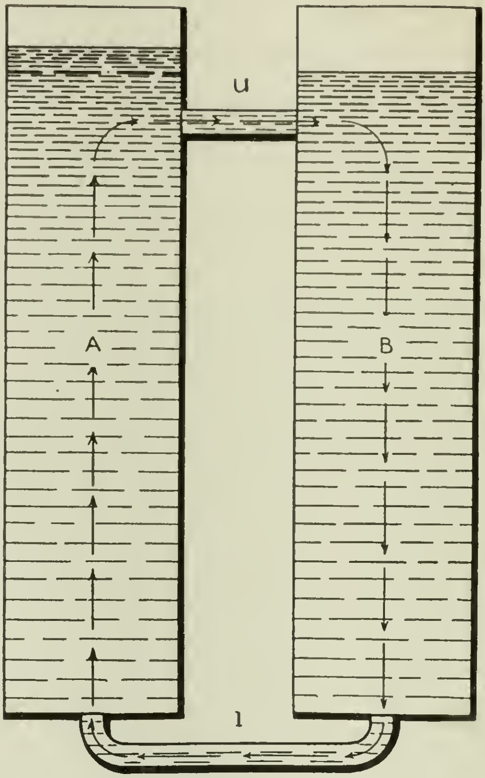
* Continued from page 408, vol. 184, September, 1917.

A. That is, since the circulation in question is a gravitational phenomenon induced by a temperature difference between the water in the two tanks, it clearly is immaterial how this temperature difference is established, whether by heating the one tank or by cooling the other. Similarly in the case of the atmosphere. If two adjacent columns of air, or the masses of air over two adjoining regions, whether large or small, are kept at different temperatures, there will exist, through the action of gravity, a continuous overflow from the warmer to the colder, and an underflow from the colder to the warmer. Neither does it make any difference in this case how the inequality of temperature is established and maintained, whether by heating the one section or by cooling the other.

FIG. 25.



Circulation between warm and cold tanks.

VERTICAL CONVECTION OF THE ATMOSPHERE.

General Considerations.—Vertical convection of the atmosphere may be divided into two classes: (*a*) mechanically forced convection, as the rise of air on the windward side of a mountain or other obstruction and its fall on the leeward side; (*b*) thermal convection. The latter, involving both warming and cooling, is by far the more important; in fact, it either constitutes or is associated with all natural air movements. It commonly is said to consist of the rising of warm air and the sinking or flowing in of cold air to take its place; but, while this describes the phenomenon of thermal convection, it seems to imply the false concept that warm air has some inherent ascensional power, whereas, in reality, thermal convection is only a gravitational phenomenon, consisting in the sinking of relatively heavy air and the consequent forcing up of air which, volume for volume and under the same pressure, is relatively light.

The terms "heavy" and "light" are used here advisedly instead of "dense" and "rare," because it is the relative *weights* of two adjacent masses of air of equal volume under the same pressure and not their *densities* that determine which shall fall and which shall be raised.

Three factors enter into the question of weight per unit volume when pressure is constant: (*a*) temperature, (*b*) composition, and (*c*) horizontal velocity, including speed and direction. The first of these weight factors varies widely and is very effective. A change in temperature by any given amount $\mp t$, say, changes the original weight per unit volume, W_1, to the new weight, $W_1 \pm w$ in the ratio,

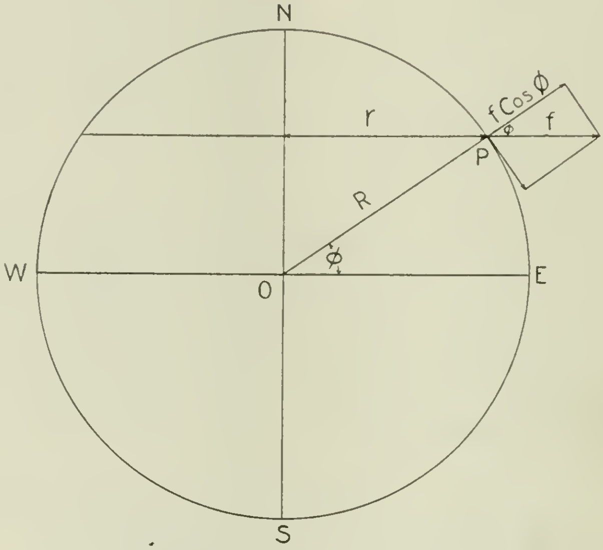
$$\frac{W_1}{W_1 \pm w} = \frac{T \mp t}{T} \quad \text{(Charles's or Gay-Lussac's law)},$$

in which T is the original absolute temperature. Thus if the original temperature is that of melting ice, and it is increased or decreased by 1° C., the weight per unit volume will be decreased or increased, respectively, 1 part in 273.

The effect of the second of the above weight factors, the composition of the atmosphere, is obvious from the following consideration: Since the number of gas molecules per unit volume under a fixed temperature and pressure is independent of the nature of the gas—Avogadro's law—it follows that under these conditions an increase or decrease of water vapor, say, in the atmosphere implies a corresponding decrease or increase of the other molecules present, mainly nitrogen and oxygen. Now the equivalent molecular weight of dry air is approximately 28.8

and that of water 18, hence a change in the water vapor, the only constituent of the atmosphere that appreciably varies, amounting to 1 per cent. of the total number of gas molecules present, alters the weight per unit volume by $\frac{108}{288} \cdot \frac{1}{100} W$, in which W is the weight of the unit volume of dry air under the same conditions of temperature, pressure, and gravity. On very warm days water vapor may amount to 5 per cent. or more of the total gas molecules present, and the air, therefore, be, roughly, 2 per cent. lighter than it would be if perfectly dry. Of course, changes from saturation to utter dryness, or the reverse, do not occur in nature, but a variation of as much as 50 per cent. in the absolute humidity at a given place does occur through evaporation, condensation, and air movement. Hence on very hot days a change of 1 per cent. in the weight per unit volume of the lower air as a result of altered composition is quite possible without change of temperature. This produces a difference in buoyancy of the same order as that caused by a 3° C. change in temperature and therefore may be decidedly important.

FIG. 26



Decrease of weight due to rotation of the earth.

The third factor that affects weight and convection, namely, horizontal velocity, while comparatively small, occasionally may be of some importance. Its numerical value can easily be computed. Let NS, Fig. 26, be the axis of the earth's rotation, and let P at latitude ϕ be the point under consideration. The centrifugal force f acting on the mass m at the point P is given by the equation,

$$f = m\ r\ \omega^2,$$

in which ω is the angular velocity, and r the distance of P from the axis. Numerically,

$$\omega = \frac{2\pi}{86,164}.$$

Since the mean radius of the earth is about 6368 kilometres, and since weight equals mass times gravitational acceleration, or $981m$, approximately, in the C.G.S. system, it follows that at latitude 40°

$$f = \frac{w}{378}, \text{ roughly},$$

in which w is the weight of the object considered, while the decrease, dw, in the weight, or the component of f at right angles to the surface, is given by the equation,

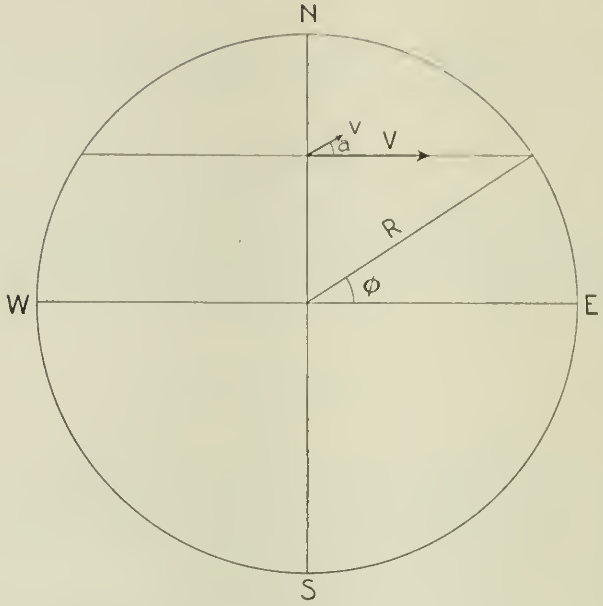
$$dw = -f \cos 40^\circ = -\frac{w}{493}, \text{ about}$$

At latitude 40° a velocity of 22.4 metres per second (50 miles per hour) from east to west is equivalent to increasing ω^2 by 1 part in 8, approximately, and an equal velocity from west to east to decreasing it a like amount. That is, at latitude 40° a given mass of air in a west wind of 22.4 metres per second (50 miles per hour) weighs less than an equal amount in an east wind of the same velocity by about 1 part in 1972. Similarly for other latitudes in proportion to their cosines. Hence, other things being equal, an east wind tends slightly to underrun an adjacent west wind.

The above special solution of this problem may suffice for most purposes, but the following outline and conclusions of a more general solution probably will be of interest.

Referring to Fig. 27, let V be the horizontal velocity of the surface of the earth at latitude ϕ, v the horizontal velocity of the air with reference to the surface, α the angle between the east direction and the path, and assume the earth to be spherical and concentrically homogeneous. Further, let mg_0 be the gravitational pull on the mass m, or the weight the mass m would have when at rest if the earth were nonrotating, and let mg be its actual weight. Then,

Fig. 27.



Change of weight due to horizontal velocity.

$$mg = mg_0 - m\frac{(V\cos\phi + v\cos\alpha)^2}{R} - \frac{m(v\sin\alpha)^2}{R}$$

$$= mg_0 - \frac{m(V\cos\phi)^2}{R} - \frac{mv(2\,V\cos\phi\cos\alpha + v)}{R}.$$

But, $mg_0 - \frac{m(V\cos\phi)^2}{R} =$ the weight of the mass m when at rest on the surface of the rotating earth. Hence, when the mass m is given a horizontal velocity v, its still-weight, W, is changed by an amount, ΔW, given by the equation,

$$\Delta W = -mv\,\frac{(2\,V\cos\phi\cos\alpha + v)}{R}.$$

Since the latitude is limited by 0° and 90°, it follows that the sign of the change (that is, whether the change consists of a decrease or increase from the still-weight) depends upon the value of α, or the direction of motion. Obviously whenever $\cos\alpha$ is positive, or the velocity has an *easterly* component, the change of weight is *negative*—maximum when ϕ and α are both zero, or when the motion is east on the equator. Similarly, since $2\,V\cos\phi$ is nearly always large in comparison with v, the change of weight ordinarily is *positive* whenever the velocity has an appreciable westward component. This increase of weight clearly is a maximum when $\phi = 0°$ and $\alpha = 180°$, or when the motion is west on the equator.

Further, the direction of the wind in order that there be no change of weight is conditioned by the equation,

$$\cos \alpha = \frac{v}{2 V \cos \phi}.$$

But, as above stated, $2 V \cos \phi$ nearly always is large in comparison with v, and therefore the direction conditioned by zero change in weight commonly has only a small westerly component. For example, let $v = 44.7$ metres per second (100 miles per hour) and let $\phi = 60°$. Then, under these somewhat excessive conditions, for zero effect, $\cos \alpha = -\frac{1}{10}$, about, or the direction along which there is no change of weight is less than 6° west of the meridian.

From the above it appears that of the three factors that alter the weight of a given volume of air and thereby determine whether it shall rise to higher levels, sink to lower, or remain where it is, temperature is by far the most important, and horizontal velocity the least important. As a rule, the former alone need be considered.

Local Convection.—There are two distinct ways of thermally inducing convection: (*a*) by *heating below*; (*b*) by *cooling above*. Each is of great importance, both in general atmospheric movements and also in those restricted or local winds to which special names have been given. Where heating alone occurs the rising air does not return, but remains in equilibrium at its new level, where its final temperature is the same as that of the adjacent atmosphere. Similarly, when cooling alone occurs the sinking air does not again immediately rise. In other words, neither heating nor cooling, acting alone, can produce closed circulation in which the same mass passes through a complete cycle of positions, though, of course, a compensating movement must occur somewhere. A strong local uprush, for instance, except in the case of the thunderstorm, to be explained below, is nearly always compensated by a wide settling, so gentle that it cannot be measured. Similarly, restricted down-rushes of air, again except in connection with the thunderstorm, are compensated by wide and gentle upward movements.

Whatever the type of atmospheric disturbance under consideration, the most important general facts to remember are: that all vertical movements of the air are accompanied by dynamical heating or cooling; that rising air cools, roughly, at the adiabatic rate of about 1° C. for each 100 metres increase of elevation; that descending air warms at substantially the same rate; that dynamic cooling limits the height of upward convection; and that in many cases dynamic heating, and not the surface of the ground, limits downward convection.

CLASSIFICATION OF WINDS.

All the above is entirely general and of universal application. Gravity and temperature differences enter directly or indirectly into all atmospheric circulation, both the fundamental and continuous circulation that exists between the warm equatorial and cold polar regions, and those secondary circulations that occur only locally and occasionally. Nevertheless, clearness in any detailed discussion of all winds requires their grouping according to some basis of classification suitable to the purpose in view—in the present case a discussion of their initiating causes and modifying influences. Unfortunately, none of the current classifications of winds (*e.g.*, those listed in Milham's "Meteorology," p. 164 *et seq.*) is adapted to this end, and therefore a somewhat different grouping provisionally will be used.

Obviously no subdivision of air movements is possible on the basis either of gravitation or of temperature difference, since, as just explained, each is involved in every such movement.

But there also are modifying factors—friction, viscosity, turbulence, local heating, local cooling, deflection by mountain barriers, deflection due to the earth's rotation, and many others that make one circulation different from another in time of occurrence, extent, duration, direction, and intensity. Hence in considering the origin and nature of winds, it will be convenient to classify them as follows, according to the conditions that initiate or materially modify them, and to discuss separately, under its appropriate head, each distinct and well-recognized subdivision.

A.—Winds due chiefly to local heating—whirlwinds, cumulus convection, valley breezes, sea breezes.

B.—Winds due to local cooling—land breezes, mountain breezes, glacier winds, bora, mistral, Norwegian fallwinds, continental fallwinds.

C.—Winds due to simultaneous adjacent local heating and local cooling—thunderstorm winds.

D.—Winds due to widespread heating and cooling—gradient winds, monsoons, trades, antitrades, tropical cyclonic winds, extratropical cyclonic winds, anticyclonic winds.

E.—Forced winds, or winds caused by other winds—eddies, foehns (Chinooks), tornadoes.

WINDS DUE TO LOCAL HEATING.

Whirlwinds.

During clear, calm summer afternoons, particularly during a dry spell when vegetation is parched and the ground strongly heated, dust whirls often develop, and occasionally travel considerable distances before becoming dissipated. The flatter the region, the more barren, the hotter the surface, and the quieter the air, the more violent such whirls become. Hence, level deserts are especially frequented by such winds, amounting at times to violent storms, though never more than a few metres in diameter. The development of these storms in which convection is strong is not simple, but an understanding of them will materially help to an understanding of convection due to heating in less obvious cases.

It is well known that those regions in which violent dust or sand whirls occur are also the places where inferior mirages are most frequent. The reason for this coincidence is the fact that the density gradient of the atmosphere essential to the production of a mirage simulating a lake, namely, an increase of density with elevation, is most favorable to strong vertical convection. Under these conditions the air is in that same unstable equilibrium that applies to a column of liquid whose under layer is lighter than the upper—whose under layer is oil, say, and upper layer water.

At first sight it might seem that no such condition of considerable extent can obtain in nature; that as soon as the under layer became specifically lighter than the one next above, they would change places. Whenever a cork, for instance, is let go under water it bobs up. Similarly, a balloon rises, without exception, whenever the combined weight of gas, envelope, etc., is less than that of the atmosphere displaced. Why then should not surface air, whenever it becomes specifically lighter than the air above it, also rise immediately? This undoubtedly is just what a limited volume of light air would do if actually surrounded on all sides by heavier air. But surface air is not completely surrounded by other air; its condition is somewhat analogous to that of a cork whose flat surface is pressed against the bottom of a vessel of water. The cork in this case does not rise, simply because it is pressed down by water above and not pushed up by water beneath. Similarly, warm air covering an extensive flat surface is pressed down by the superincumbent atmosphere and not pushed up by denser air below—there is no denser air below to push it up.

Obviously, though, even surface air under the given conditions is in an unstable condition. Hence it is important to determine that vertical temperature gradient which reduces superadjacent layers of air to the same density.

Auto-convection Gradient.—Suppose the atmosphere is perfectly quiet, what temperature gradient must any layer of it have in order that it may just initiate its own convection?

Clearly this gradient must be such that density shall just increase with elevation. That is, the ratio, $\frac{d\rho}{hd}$, must be just positive.

From

$$pV = \frac{p}{\rho} = RT$$

we get

$$\rho = \frac{p}{RT}.$$

Therefore,

$$d\rho = \frac{p}{RT}\left(\frac{dp}{p} - \frac{dT}{T}\right).$$

But

$$dp = -981\ \rho dh = -\frac{981\ dh}{V} = -\frac{981\ pdh}{RT}.$$

Therefore,

$$d\rho = -\frac{p}{RT}\left(\frac{981\ dh}{RT} + \frac{dT}{T}\right).$$

and

$$\frac{d\rho}{dh} = \frac{p}{RT^2}\left(\frac{981}{R} + \frac{dT}{dh}\right).$$

Hence, since $\frac{dT}{dh}$ is negative in the case under consideration,

$$\frac{d\rho}{dh}=0,$$

when

$$\frac{dT}{dh}=\frac{981}{R}.$$

But for dry air,

$$R=2.871\times10^6$$

and

$$\frac{dT}{dh}=-0.0003417.$$

Hence when $dT=-1^\circ$ C., $dh=29.27$ metres.

That is, in order that an under layer shall have the same density as the next above it the temperature must decrease 1° C. with each 29.27 metres increase of altitude, or 3.52 times faster than the adiabatic rate of 1° C. per 102.93 metres. In order that the lower layer shall be distinctly lighter than the upper, the temperature decrease with increase of altitude must be four or five times the adiabatic rate.

Obviously an extensive layer of warm, light air cannot all rise at the same time. It must rise locally and in streams, if at all. Similarly, the upper air must settle locally, if at all. But during the time mirage conditions are maintained the surface is strongly heated, so that any air that might reach it is not only warmed dynamically by the compression to which it is subjected, in settling down, but also by the heat acquired from contact with the surface. Hence, any settling of colder air from above amounts only to a partial removal of the hot and therefore light surface air.

It might seem, however, that the streams of rising air, above referred to, would ascend with great rapidity and in such volume as quickly to exhaust the supply of warm air. But, as already stated, the heat is being constantly supplied, and therefore the surface layer of hot air continuously renewed. Besides, the difference in weight between a given volume of a rising filament of warm air and an equal volume of adjacent air is at first only an exceedingly small fraction of the weight of either. Hence the acceleration with which it moves is correspondingly small. In nearly all cases the feeble streams of rising hot air presumably are pinched off by the adjacent denser air, and in this manner the breaks, as it were, in the integrity of the hot surface layer mended and the entire convection divided into innumerable discontinuous filaments—mere fitful leaks from the constantly renewed reservoir of hot air.

It occasionally happens, however, that because of some disturbance an unusually large volume of warm air breaks through and rises in a columnar form. Such a column necessarily produces a chimney-like draft, since the air composing it is warmer and therefore lighter than the adjacent air on the outside. Hence, however established, such a column of warm air will maintain its integrity, or, rather, perpetuate itself, so long as the air that is forced into it from the base is warm and light. In this connection it apparently cannot be too strongly emphasized that the ascending air is not "drawn" up any more than air is "drawn" up a chimney. In each case the weight of the column of warm air is less than the weight of an adjacent equal column of cooler air, and the static unbalance is compensated kinetically; that is, air is forced up the column in question, as up a chimney, because of, and in proportion to, the difference between its density and that of the cooler descending air outside. Even a *vena contracta,* or restricted section, is formed in the column a short distance—one to five metres often—above the surface, as, and for the same reason that, such a restriction occurs in a jet of any fluid shortly after its issuance from an ordinary orifice.

The incoming air is almost certain to be directed to one side of the centre of the rising column, and, as the angular momentum thus established tends to remain constant, a correspondingly vigorous whirl is developed as the place of ascent is approached that gathers up such loose materials as dust, straws, leaves, etc. Furthermore, this rotation, whether clockwise or the reverse, perpetuates itself, though the details of how it does so are, perhaps, not fully understood. Pictet,[30] for instance, reports observing a dust whirl near Cairo, Egypt, that began on a small sand mound, remained stationary for nearly two hours, then, in response to a gentle breeze, wandered away, but maintained its sharply defined outlines and great altitude until lost in the distance, more than three hours later, or about five and a half hours after its inception.

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[30] Hildebrandsson et Teisserenc de Bort, "Les Bases de la Météorologie dynamique," vol. 2, pp. 286–288.

The diameters of these whirls (seldom more than a few metres near the ground) are too small for the direction of their gyration to be greatly influenced by the rotation of the earth. Hence nearly as many turn in one sense as in the other. They have even been reported to reverse, but it is probable that the apparent changes were only optical illusions similar to that which causes the cup anemometer to seem to reverse its rotation.

The height to which the whirling column rises (that is, the distance between the base of the column and its mushroom capital), the violence of the whirl, and, in some measure, even its duration, all depend upon the amount of surface heating and the extent to which the lower temperature gradient has been made greater than the adiabatic. When this heating is slight, only those small and gentle dust whirls with which all are familiar can be generated and sustained. When, however, the heating is pronounced, as it often is over level, desert regions, the whirl may assume almost tornadic violence. But, however violent, this sort of storm is never a tornado; it originates near the surface and is sustained by the supply of warm air from below, while the true tornado is generated and developed by conditions that obtain at the cloud level.

When dust whirls pass on to regions where the surface air is not so strongly heated—over bodies of water, for instance, or green vegetation—they no longer are fed with air relatively so light and, as a rule, quickly come to rest. Naturally, too, their frequency varies with topography, ground covering, latitude, season, and time of day. Thus they are most frequent of afternoons and least of early mornings, most likely to occur during summer and fall and least during winter and spring; most generally found in tropical and semitropical countries and least in regions of high latitude; more numerous over barren surfaces than over water and succulent vegetation; and, finally, more favored by level regions than by irregular and broken ground.

Cumulus Convection.

An interesting and important case of rapid vertical convection resulting from the local application of heat and consequent establishment of strong horizontal temperature contrasts is that displayed by the turbulence of the cumulus cloud. That strong vertical and irregular movements of the air often occur in large cumulus clouds is known from the rapid boiling and rolling motions of their upper portions, from the descriptions of balloonists who have been caught up in the heart of a thunderstorm, and from the formation of hail within them. This latter phenomenon, the formation of hail, implies very definitely an uprush of at least 8 to 10 metres per second (20 miles per hour). This, in turn, on the theory of the chimney-like action of a warm central column of air, would demand, even neglecting viscosity, the equivalent of a column 1500 metres high and 1° C. warmer throughout than the surrounding atmosphere at the same level.

The chief cause of the horizontal temperature contrasts necessary to this rapid uprush obviously is the difference between the current temperature gradient of the surrounding atmosphere and the adiabatic gradient of the saturated air within the cloud itself, full details of which will be given in the chapter on the thunderstorm.

The common level, therefore, of a considerable number of detached but neighboring cumuli is one of rather vigorous convection—up within the clouds and down between them—however free from turmoil the atmosphere may be at other altitudes.

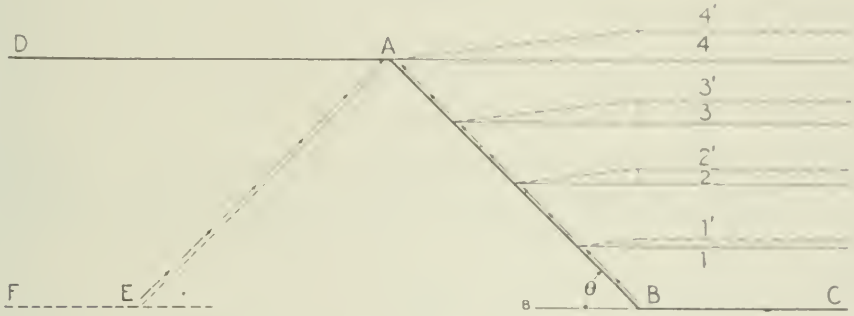
Valley Breeze.

During warm, clear days, when there is but little or no general wind, a gentle breeze, known as the valley breeze, commonly blows up the sides of mountains. The strength of this breeze varies greatly, owing to the size of the mountain, the material of its covering, and the conditions of its surroundings. The cause of some of these variations can be understood by reference to Fig. 28.

Case 1.—Mountain Slope Connecting Wide Plateaus of Different Level.—Let *AD* be the upper plateau, *BC* the lower, and *AB* the slope connecting them. Further, let the insolation be vertical, or the sun directly overhead. If now the slope *AB* is barren, or nearly so, it will become strongly heated and the adjacent air correspondingly expanded. As this lighter air is buoyed up by the adjacent denser atmosphere there results a draft in toward the side of the mountain. But this draft is all along the mountain slope from top to bottom, and thus in a measure the warm air is held in against the mountain side. Hence, the updraft along the side of the mountain is analogous to that in a chimney.

In addition to this obvious chimney effect of the mountain, there is, in the case under consideration, another source of upward winds that causes them to blow up along even shaded and cool ravines, unless snow-filled and very cold, in which circumstance local density is the controlling factor and air drainage, or a downward flow of the air, usually prevails, as will be more fully explained later. The early morning isobaric levels, 1, 2, 3, etc., are raised by heating during the day to higher levels, 1′, 2′, 3′, etc. From any point directly above the foot of the mountain the amount of this expansion obviously drops off, as indicated in the figure, as the side of the mountain is approached. Hence a pressure gradient is established toward the mountain side and plateau beyond. If both plateaus are broad, a perceptible breeze of several hours' duration up the mountain slope and onto the higher plateau may be induced in this manner. Such winds grow stronger as the top of the mountain is approached. At night, after sufficient cooling has taken place, the winds reverse.

FIG. 28.



Effect of mountain on levels of isobars.

To form some idea of the possible magnitude of these effects, let the difference in level between *AD* and *BC* be 1.6 kilometres (one mile), and let the air between these levels be warmed on the average 5.5° C. (10° F.), then the increase of barometric pressure at *A* will be about 2.5 mm. (0.1 inch), with proportionate increases along the side of the mountain—quantities quite sufficient to produce a decided breeze.

Similar overflow winds occur also on the slopes of the isolated mountain, *BAE*, whenever the air on the opposite sides is unequally heated. Thus the landward side of a coast mountain, for instance, on a still warm day should have a breeze blowing up it and out to sea.

Case 2.—Isolated Mountain in the Midst of a Uniformly Heated Plain.—Here, too, the sides of the mountain are heated and corresponding upward currents induced. There also is expansion of the air over the adjacent plains and a tendency to establish pressure gradients towards the mountain, as in the case just discussed. But, however great this expansion, the gradients thus produced never cause, in the present case, more than a negligible wind. To make this statement obvious: Let the ridge *A* of the mountain be 1.6 kilometres (one mile) above the plains *EF* and *BC;* let the width of the base, *EB,* be 3.2 kilometres (two miles), and let the air be heated the same over one plain as over the other. Let the temperature increase of the air during the day be 5.5° C. (10° F.), or, suppose, 1 part in 50 of the absolute temperature. Under these conditions the compensating flow of air from the two sides must amount jointly to 1 part in 50 of the volume of the mountain; that is, the horizontal flow of the air from either side of the given mountain must average, from top to bottom, 1 part in 50 of 0.8 kilometre (0.5 mile). If, further, this is extended over a period of ten hours, as it may well be, the average velocity will amount to only about 1.5 metres (5 feet) per hour—certainly an imperceptible breeze.

Clearly, then, the breezes that ascend mountain sides on still clear days have two causes: (*a*) a chimney or draft effect due to surface heating—always present—and (*b*) a pressure gradient effect due to expansion of the air over an adjacent plain or valley—present only when this expansion is unequal on the opposite sides of the mountain, or when the base levels are decidedly unequal on the opposite sides.

Sea Breeze.

Whenever a strongly heated region adjoins one whose surface is less heated, a local circulation from the one to the other obtains, unless prevented by winds of a general circulation. Thus along the seashore, beside lakes and even at the edge of favorably situated forests, a breeze (sea breeze, lake breeze, and forest breeze, respectively) of greater or less strength sets in during dry summer forenoons, after the land surface has become sufficiently warmed to establish decided convection.

Since the sea breeze obviously ceases at that level where the barometric pressure is the same above the land that it is above the water, and since the change of pressure with change of altitude is a function of temperature, it follows that its depth, never great, may easily be computed by replacing certain general terms of a suitable equation by observed temperature and pressure data. To develop such an equation:

Let ρ be the density of the air, then

$$-dp = \rho\, g\, dh,$$

in which $-dp$ is the small decrease in pressure corresponding to the small increase, dh, in height, and g the gravitational acceleration.

From the general equation,

$$pV = RT = \frac{p}{\rho},$$

in which p is the pressure, V the specific volume, R the gas constant, and T the absolute temperature, it follows that

$$\rho = \frac{p}{RT}.$$

Therefore,

$$-\frac{dp}{p} = \frac{g\, dh}{RT}.$$

Hence, integrating from p_0, corresponding to $h = 0$, to p, corresponding to $h = h$, if T is independent of h, which, as a first approximation, its average value may be assumed to be,

$$\log_e \frac{p}{p_0} = -\frac{gh}{RT}.$$

The value of the first half of this equation obviously remains the same when the corresponding, but more convenient, barometric readings b and B are substituted for p and p_0, respectively. Hence, also,

$$\log_e \frac{b}{B} = -\frac{gh}{RT}.$$

But the top of the sea breeze clearly is where there is no horizontal difference of pressure, or where $db = 0$, when h is constant. Hence, on differentiating this equation, keeping h constant, it is seen that

$$db = dB\left(\frac{b}{B}\right) + \frac{bgh}{RT^2}dT,$$

and that the depth of the breeze, h, is given by the equation,

$$h = -\frac{dB}{dT}\,\frac{RT^2}{gB}.$$

Consider a typical case: Let the sea-level reading of the barometer on land, less that at sea, or $dB = 0.5$ mm.; let the temperature over the land exceed that over the sea by $dT = 5°$ C.; let $T = 300°$ A.; let B, the sea-level barometer reading at sea, be 760 mm. R for dry air $= 2.871 \times 10^6$. Then the depth or thickness, h, of the sea breeze is given by the equation,

$$h = \frac{0.5}{5}\,\frac{2.871 \times 10^{10} \times 9}{981 \times 760} = 34{,}675 \text{ cm.} = 347 \text{ metres, approximately.}$$

The sea breeze, usually, as just explained, not more than 500 metres deep, starts on the water, seldom attains a greater velocity than 4.5 metres per second (10 miles per hour: the greater the temperature contrast the stronger the breeze), and extends inland, growing feebler and warmer, to a distance of only 16 to 40 kilometres (10 to 25 miles).

In a very important sense the circulation involved in this and all other local air convections is incomplete, since in such cases the path along which a given particle of the atmosphere flows is open and not closed. That is, the air that goes up over the heated land, in the case of the sea breeze, for instance, does not itself return by way of the water; it simply spreads out at the top of its ascent where its new temperature (above assumption of constancy of temperature not strictly correct), acquired by adiabatic expansion, is the same as that of the adjacent atmosphere, while the return branch, or down-flowing portion of the circulation, is broad and gentle. Hence the surface air always flows from the cooler toward the warmer mass. By day the sea or lake breeze is on shore, because the soil gets warmer than the evaporating water, and the similar forest breeze, always feeble, away from the woods.

WINDS DUE TO LOCAL COOLING.

Land Breeze.

By night, when the direction of the horizontal temperature gradient is the reverse of that during the day (that is, when the water surface is relatively warm and the soil cool, because of its rapid radiation), the direction of the surface wind is also reversed or offshore. This is the well-known land breeze.

Besides being reversed in direction and occurring at night instead of by day, the land breeze further differs from the sea breeze in usually being very much the weaker of the two, even though aided by the gravity flow of the cooler surface stratum of air. This is because *a*, the temperature contrast between land and water, is less by night than by day, and *b*, the surface friction over land which retards the land breeze, is greater than the water friction that affects the sea breeze. Hence, while the latter, as above stated, reaches 16 to 40 kilometres (10 to 25 miles) inland, the former seldom extends more than 8 to 10 kilometres (5 to 6 miles) to sea.

The depth of the land breeze, usually less than that of the sea breeze, obviously may be computed in precisely the same manner as the latter.

Mountain Breeze.

During clear nights, when there are only gentle winds or none at all on the tops of hills and mountains, there usually is a movement of the air down the sides and along the basin of every valley, most pronounced in ravines and along the steeper slopes. When the valley is long and steep and free from forests, especially if covered with snow, and when the flow is augmented by the influence of an adjacent cyclonic or anti-cyclonic system, the current of down-flowing air may attain the velocity of a gale and become, in fact, a veritable aerial torrent. The mountain breezes in such cases are a part of general wind systems, and in some localities have been given special names, such as the Bora, for example. The gentler winds of this class are known indifferently as the mountain breeze or mountain wind. In discussing a general class of descending winds to which he gives the name *Katabatic* winds, Shaw [31] gives the following elegant description of the mountain breeze:

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[31] Sir Napier Shaw, "A Barometer Manual for the Use of Seamen," 8th ed., 1916, p. 23.

"At night there is a natural tendency, easily explained, for the air to get calm at the surface because it gets cold. On clear nights the whole landscape gets cooled by radiation, and the air is cooled still further. As it cools it runs down the hill like water until the whole valley becomes filled with a river of air flowing down towards the sea.

. . . .

"It may be allowed that the air gains in temperature by 1° for every 190 feet of drop, and that the rise of temperature will diminish the density of the falling air. That will diminish and may stop the flow, but if the air is sufficiently chilled to start with and gets further chilled by a cold surface on the way, very violent winds may be produced. It may be of interest to suggest that the speed attained depends upon how long the flow is kept up. When it first begins, the falling front has to push the air beneath it out of the way, but when the current is established from top to bottom, there is only the surface friction to retard it, and the terminal velocity will approach to that given by the ordinary formula $v = \sqrt{2\,gh}$; if the velocity is to be given in feet per second, v becomes equal to $8\sqrt{h}$."

Glacier Winds.

It is well known that a draft of cold air often is found blowing out from a cave-like opening in the lower end of a glacier, hence called glacier wind. Similar winds, blowing out during summer and in during winter, occasionally are found at the mouths of caves, called blowing caverns, on the sides of hills or mountains. In the volcanic mountains of Japan such places are numerous and extensively used for cold storage.[32] In each case the explanation of the phenomenon is the same and obvious. The cavity extends quite through the glacier, or earth, as the case may be, from its lower to its higher openings. Let this difference in elevation be 250 metres; let the average temperature of the air inside the cavity be 0° C., and of that outside at the same level 15° C. The density of the inner air will be to that of the outer approximately as 19 to 18, and the pressure head, producing an inverse chimney effect, about 14 metres. Neglecting friction—usually, however, an extremely important factor—this would give the exit air a computed velocity of about 16.6 metres per second (37.1 miles per hour)—a very appreciable gale. The velocity or strength of this wind, other things being equal, varies as the square root of the difference in level between the lower and upper openings.

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[32] S. Suzuki and T. Sone, Tohoku Univ. Sci. Reports, 3, pp. 101–111.

In the case of a glacier, drainage obviously obtains in substantially the same manner, whether the air passes in a concentrated stream through a cavity or along a crevice within the ice, or merely flows in a broad sheet over the top surface. Clearly, too, the same sort of aerial cascades (exaggerated mountain winds) must occur, especially during summer nights, over any banks of snow that may exist in the upper and steeper reaches of canyons and mountain valleys. Such winds necessarily are shallow and therefore, when swift, a treacherous source of danger to the landing aviator.

The Bora.

From the above explanation and examples of aerial drainage it is obvious that similar winds must often blow down steep slopes that separate high, snow-covered plateaus or mountain ranges from adjacent bodies of relatively warm water. Thus when an anticyclone covers such a region during winter the surface air becomes very cold and correspondingly dense until, unless otherwise dissipated, it overflows restraining ridges or drains away through passes and gaps. Clearly, too, this flow must be most frequent and strongest during the early morning, since that is the coldest time of the day, and least frequent of mid-afternoons. In many instances during anticyclonic weather the air as it leaves the snow fields is so cold that in spite of dynamical heating it even reaches the sea at freezing temperatures and very dry. When, however, the drainage is amplified, if not even started, by the pressure gradients (to which the final velocity bears no special relation) due to a properly situated " low," it usually is associated with a counter cyclonic current above and therefore accompanied by rain, sleet, or snow.

Probably the best known of all these violent fallwinds is the *bora* of the northeast Adriatic, especially at Trieste, Fiume, and Zengg. The boras of these places, however, are not from the north, as the name implies, but rather from the northeast and east-northeast.

Another excellent example of this kind of wind occurs at Novorossisk, a Russian port on the northeast coast of the Black Sea, where it blows down from a nearby pass in the mountains, occasionally with destructive violence. Probably, also, the brief but sudden and violent williwaws of steep, high latitude coasts have a similar origin.

Mistral.

Another instance of convection due essentially to cooling is the well-known mistral, or dry, cold northerly wind of the Rhône Valley. Here the more or less persistent winter low over the warm waters of the Gulf of Lyon to the south and the frequent highs over the snow-covered plateaus of southeastern France to the north often coöperate in such manner as to produce extensive air drainage down the lower Rhône Valley. In general the cause of the mistral and its actions are the same as those of the bora. It is less violent, however—its path less steep, and therefore itself not so distinctly an aerial cataract. Similar winds occur, of course, under like circumstances in other parts of the world, but the mistral is the best known of its class.

Norwegian Fallwinds.

An extensive fallwind, which, because of its importance and the fact that it is more or less unique, deserves especial mention, frequently occurs during winter along the coast of Norway. Sandström,[32] in one of his interesting atmospheric studies, describes it as follows: " In winter, as one steams along the northwest coast of Norway, there is frequent opportunity to observe a peculiar meteorological phenomenon. Fine weather prevails over a narrow strip along the coast, while a heavy bank of cloud is visible out to seaward. Of course, coastwise traffic is greatly favored by this fine-weather strip and takes full advantage of it. Throughout this zone of fine weather prevails a cuttingly cold wind so strong that one can scarce stand against it when on deck. The maximum velocity of this wind is attained near shore, where the water is whipped up into whirls and miniature waterspouts. Evidently the wind here plunges down upon the water from above, and with great force.

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[32] Mount Weather Bulletin, 5, p. 129, 1912.

"Upon leaving the steamer and travelling inland up the mountain slopes on skis, strong head winds oppose progress. This easterly wind is still very strong on the great divide of the Scandinavian Peninsula. But observations of the cloud caps on the highest peaks of the range show that a westerly wind is blowing at those great altitudes. It is clear that a lively interchange of air between the North Atlantic Ocean and the continent is taking place above the Scandinavian highlands. This exchange takes place along either side of a glide surface whose altitude above the ground at the divide may be estimated at about 1000 metres. In fact, at the kite station Vassijaur it proved almost impossible to raise the kites above that level, evidently because they there encountered a glide surface through which they cannot pass, since the wind has opposite directions on the two sides of this surface, and therefore calm must prevail at the glide surface itself. The altitude of this glide surface decreases to the Atlantic Ocean. The air below this surface flows toward the west, and above the surface it flows toward the east."

Continental Fallwinds.

From the above discussion of winds that result from surface cooling it is obvious that they are of very general occurrence, especially during cold weather and down the valleys and slopes of high, snow-covered regions. Hence one would expect drainage winds to obtain to a greater or less extent during winter over the middle and high latitude regions of every continent. Where the elevation and slope are slight, however, as they are, with but minor exceptions, over all North America east of the Rocky Mountains, over Russia, and over Siberia, except the eastern portion, this drainage necessarily must be comparatively sluggish.

On the other hand, there are two regions of continental extent—Greenland, with an area of about 827,000 square miles, and Antarctica, with an area of, roughly, 4,600,000 square miles—that are ideally located for, and perfectly adapted to, the production of strong and almost continuous fallwinds.

Greenland, as is well known, is continuously covered with an enormous ice cap that rises to a gently rounded plateau of, roughly, from 2000 to 3000 metres (7000 to 10,000 feet) elevation. This plateau, whose crest runs approximately north and south, has been crossed several times—six in all—at as many different places, and in each case nearly constant down-slope or drainage winds of greater or less strength were experienced.

Throughout its great area, therefore, Greenland is a region of almost perpetual aerial cascades and cataracts. The continuous refrigerative influence of its enormous ice cap, covering an area 18 times that of the state of Pennsylvania and rising at places to an elevation of over three kilometres (two miles), not only controls the direction and velocity of nearly all local winds, but obviously must be of decided influence on the general circulation of the middle and higher latitudes of the whole northern hemisphere—an important circumstance that will be taken up later.

Antarctica, according to the reports of all its explorers, is quite as completely covered with ice as is Greenland, and it also rises, more or less dome-like, to fully as great altitudes. Hence it would seem that its general effect on the movement of the air must be very similar to that of its great counterpart in the northern hemisphere—an inference now fully borne out by the many accounts and records of those who have skirted its coasts, crossed its plateaus, or wintered on its borders. Sir Douglas Mawson, for instance, who spent many months during 1912–13 at Adelie Land, latitude 67° S., on the edge of the continent almost directly south of Tasmania, reports an average wind velocity for an entire year, from the interior toward the sea, of more than 22.4 metres per second (50 miles per hour). "Day after day," he says, "the wind fluctuated between a gale and a hurricane." Velocities of 100 miles and over per hour occurred, and gusts of even much greater velocity occasionally were recorded. These measurements were made at the main station on the declivitous border that connects the inner ice plateau with the ocean. Back some distance inland, where the slope is gentle, the winds were less severe. At sea, also, these continental drainage winds decreased in intensity with increase of distance from shore, and ceased altogether at a distance of about 300 kilometres (187 miles), where the westerlies became effective. Obviously, therefore, this particular station was located in one of the windiest places in the world—in an aerial cataract where the cold drainage air of the ice plateau rushes down a steep coastal slope to the sea.

Similar winds of varying intensity and irregular duration are reported all along the Antarctic border, from every inland station and from end to end of every exploring trail. Clearly, then, the winds of Antarctica, though due essentially to cooling, nevertheless, because of the extensive area they cover, belong also to those great circulations that are strongly influenced by earth rotation, and therefore constitute an important part of the general circulation of the atmosphere, under which head they will again be considered.

(*To be continued.*)

Gear Ratios for Cars in City Service. ANON. (*Electric Railway Journal*, vol. 50, No. 4, p. 132, July 28, 1917.)—The only effect of a low gear ratio, or the use of large pinions in city service, is to provide high maximum speed, which has no value, and provides this high speed at the expense of energy consumption and schedule speed, which have great value. The capacity for high maximum speed does not necessarily produce high schedule speed; in other words, a city car's ability to run fast is usually worthless as a time saver.

That the very definite laws governing gear ratios for city service should be disregarded to the extent that companies retain the numerous 16-tooth and 17-tooth pinions that are in operation to-day under congested traffic conditions may perhaps be due to the complication arising from the common custom of considering both distance and time elements in connection with the subject of city car movement. However, consideration of only the time element is quite feasible. Thus it may be said that the reason why high maximum speed is worthless in city service is that the stops come at intervals of only about 40 seconds, or some other figure of that order. If a 6-second stop is assumed, the next time interval devoted to the movement of the car between stops becomes 34 seconds, and even with straight-line acceleration and braking at a rate of 1.5 m. p. h. p. s., the maximum speed that the car could attain would be 25.5 m. p. h. That is, with 34 seconds devoted to car movement, only 17 seconds could be allowed for acceleration, the remainder having to be reserved for braking in order to make the next stop. Even if the car were geared to make 30 m. p. h. and had motors large enough to accelerate at 1.5 m. p. h. p. s., with that gearing it would be impossible to attain the 30-mile speed.

If a pinion small enough to reduce the maximum speed from 30 m. p. h. to 22.5 m. p. h. should be installed, the rate of acceleration would obviously be increased to 2 m. p. h. p. s. With the same braking rate of 1.5 m. p. h. p. s. as before, and the same number of stops, the whole advantage gained by the smaller pinion may be applied to saving energy. In this case power may be shut off after 9.75 seconds of acceleration, allowing the car to coast for 12.25 seconds, and then applying the brakes for 12 seconds the run may be completed in the same time interval as before. The saving of energy will be 43 per cent., because of the greatly reduced time during which power is applied. In cases where stops are reasonably frequent, city cars now fitted with pinions of 16 or more teeth may with advantage be fitted with smaller pinions. The change, for example, even from a 16-tooth pinion involves about 6 per cent. less time on resistance, and that alone in the course of a year effects a saving of about $20 per car. The capital expense is, of course, nothing, provided the change is made at the time when worn-out gears are being replaced.

Modified Pitot Gives High Accuracy. ANON. (*Engineering News-Record,* vol. 78, No. 11, p. 570, June 14, 1917.)—The pitot tube has long been used as a device for measuring the flow of liquids and gases, but only when used with the utmost care have the results proved uniform. Fundamentally the pitot tube consists of a U-tube one leg of which enters the stream normally to the direction of the flow, while the other leg is bent around so that the cross-section of the tube faces the direction of flow. The difference in height to which the liquid rises in the legs of the U-tube represents the velocity head of the stream. The velocity computed from this head entails a variable coefficient whose value is subject to some uncertainty.

With a view to eliminating this defect, Prof. H. A. Thomas has devised what may be termed the "Hydraulic Shunt-Flow Tube," which is described in the March issue of the *Rose Technic,* page 176. In this device, as before, one leg of the U-tube enters the stream normally to the direction of flow, but the other leg communicates with a tube placed within the stream parallel to the direction of flow, through which discharge takes place. If this discharge be so governed that the pressure heads in both branches of the U are alike, the conditions of flow in the main stream and discharge tube are identical and the velocity of the stream may be deduced from the quantity discharged, the area of the tip opening, and the tip coefficient. It is possible to demonstrate that turbulent flow should not affect the coefficient of this tip. Theoretically the tip-coefficient should be unity, but a series of experiments undertaken with this in view show that it varies less than 4 per cent., while the pitot coefficient under like conditions varies more than 4 per cent.

MODERN DYNAMO ELECTRIC MACHINERY.*

BY

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ROTARY CONVERTERS.

One of the most interesting developments in the last few years is that of the sixty-cycle rotary converter.[25] Up until 1909 the record of these machines was so poor that many operating engineers preferred the motor-generator set in spite of the fact that it cost more, had a lower efficiency, and occupied more space. Many improvements, however, have been made in the last eight years, both in design and in construction, with the result that for voltages less than 750 the sixty-cycle rotary is being installed in large numbers. The Aluminum Company of America has installed eighteen of these machines, each with a normal capacity of 2500 kilowatts, in its new plant at Messina.[26]

Theory of Operation.—In order the better to understand the problems involved in the design of modern rotary converters it will be advisable to review the theory of operation of the polyphase machine.

The diagram in Fig. 82 represents a two-pole direct-current generator with the armature winding tapped at six points to form a six-phase converter, which converter is connected to a three-phase line through transformers, the diametrical connection being used. If three-phase alternating voltages are applied to the primary side of the transformers, the converter will run as a synchronous motor, but at the same time a direct voltage will be found between the brushes $B+$ and $B-$ just as if the machine were the direct-current generator of a motor-generator set. If the brushes are connected to an external circuit and a direct current is drawn from the machine, equivalent alternating currents will be drawn from the alternating-current mains just as if the machine were the synchronous motor of a motor-generator set. The resultant current in an armature conductor at any instant is the difference between the motor and the generator currents that are flowing in the conductor at that instant.

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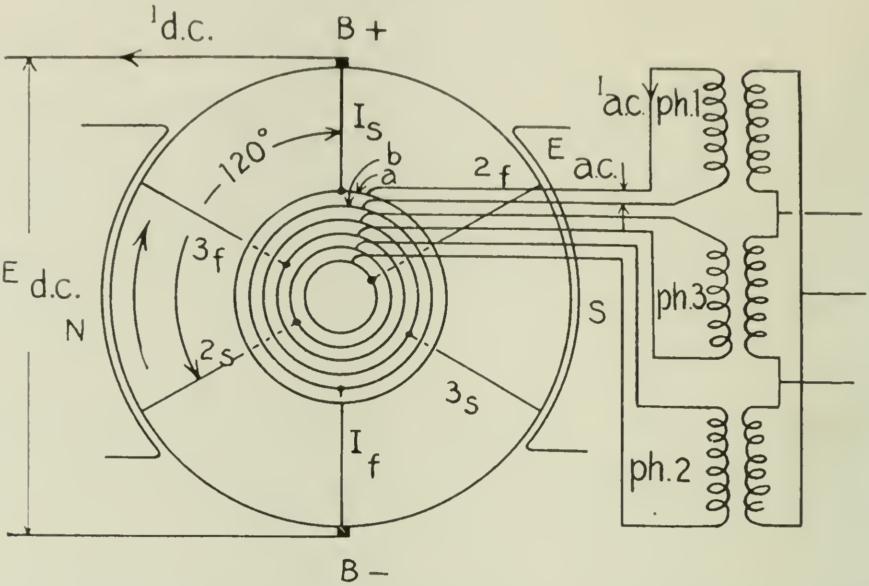
* Concluded from page 433, September issue.

[25] "The Engineering Evolution of Electrical Apparatus," by Newbury, *Electric Journal,* vol. 12, p. 27.

[26] "45,000-kw. Synchronous Converter Substation," by Burnham and Muir, *General Electric Review,* vol. 18, p. 873.

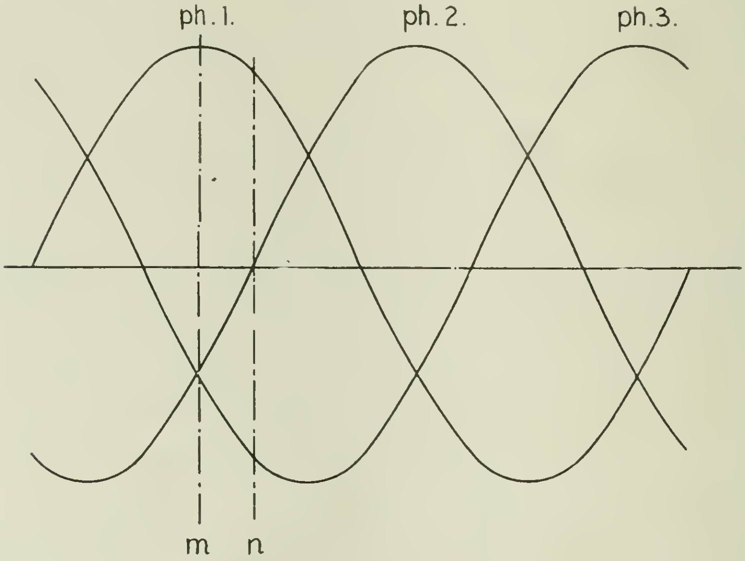
Voltage and Current Relations.—There is a fixed ratio be-

FIG. 82.



Six-phase rotary converter connected to a three-phase line by the diametrical connection of transformers.

FIG. 83.

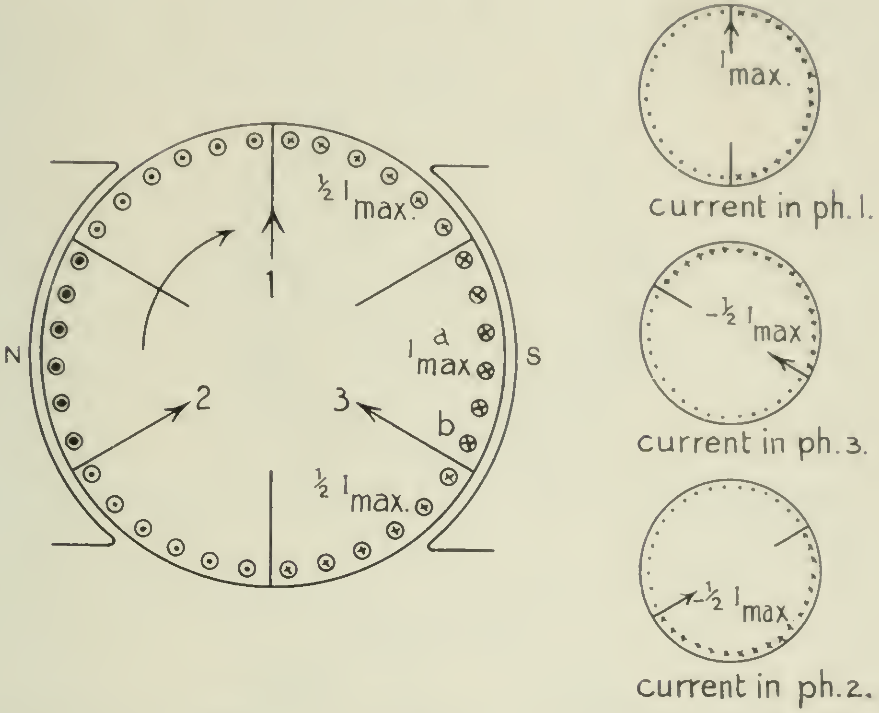


Currents in the three-phase leads of a six-phase rotary converter.

tween E_{ac}, the back-generated alternating voltage, and E_{dc}, the generated direct voltage, because both are caused by rotation in the same magnetic field. In Fig. 82 the back-generated voltage between the slip rings *a* and *b* has its maximum value when the armature is in the position shown, but the voltage between these two rings at that instant is also equal to E_{ac}, the voltage between the brushes, so that

$$\begin{aligned} E_{dc} &= \text{maximum value of } E_{ac} \\ &= \text{effecive value of } E_{ac} \times \sqrt{2} \end{aligned}$$

FIG. 84.



Distribution of alternating current in the winding at the instant *m*, Fig. 83, the winding being connected six-phase, as in Fig. 82.

For this particular type of rotary converter we also have the relation

$$E_{dc}I_{dc} = 3 \times E_{ac} \times I_{ac} \times \text{effic.} \times \text{power factor}$$

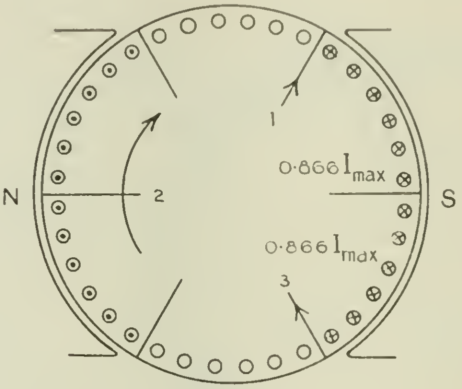
or

$$I_{ac} \text{ effective} = 0.47 \times I_{dc} \times \text{effic.} \times \text{power factor}$$

Armature Reaction.—Consider the case where the field excitation is so adjusted that the rotary is operating on the alternating-current side as a synchronous motor at 100 per cent. power factor. Under these conditions the current in each phase of the winding reaches a maximum at the same instant as the back-generated voltage in that phase, but is directly opposed to it. At the instant the voltage in phase 1 has its maximum value the armature is in the position shown in Fig. 84, the currents in the three phases have the values shown at *m* in Fig. 83, the distribution of current in each phase of the winding is as shown in the three diagrams in Fig. 84, and the resultant distribution of current in the winding due to all three phases is also shown. The armature reaction is cross-magnetizing as in a direct-current machine.

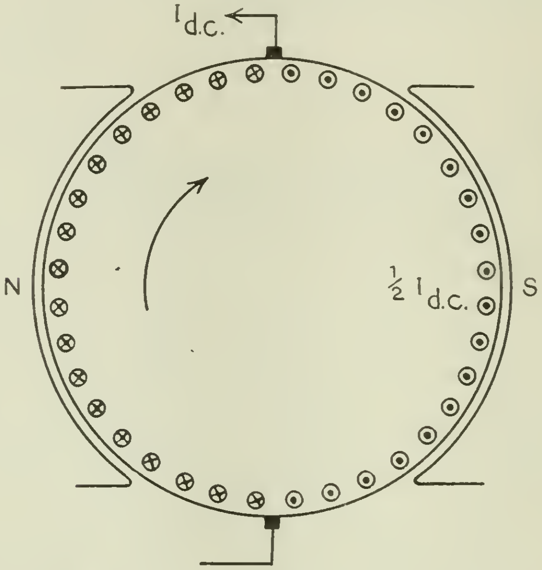
It is generally assumed that the armature field of a polyphase synchronous motor is constant in magnitude and is fixed in direction relative to the main poles; let us examine the field at the instant *n,* Fig. 83, when the current in phase 2 is zero. The armature is then in the position shown in Fig. 85, and the resultant distribution of current in the winding due to all three phases gives a magnetomotive force in the same direction as in Fig. 84.

FIG. 85.



Distribution of alternating current in the winding at the instant *n*, Fig. 83.

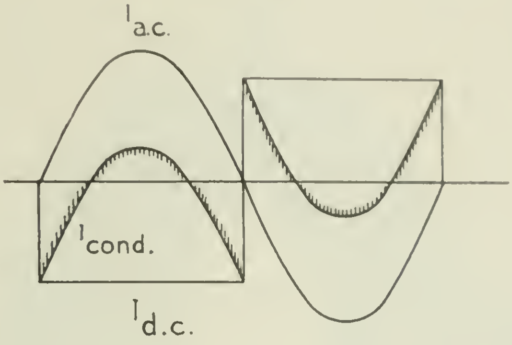
FIG. 86.



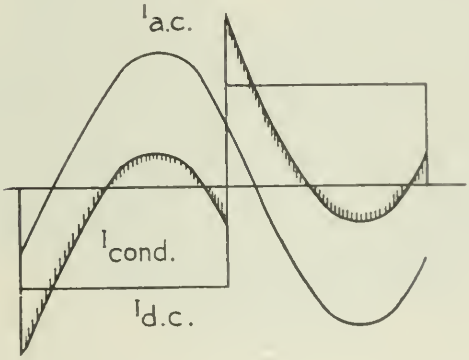
Distribution of direct current in the winding at any instant.

If the machine were acting as a direct-current generator, the direction of the currents in the conductors would be as shown in Fig. 86, and if this latter diagram be superimposed on either Fig. 84 or 85 it will be seen that, so far as commutation is concerned, the rotary converter is like a partially compensated direct-current generator; also, that the average copper loss per conductor is less than that of the same machine operating as a direct-current generator, because, as already pointed out, the resultant current in each armature conductor at any instant is the difference between the direct and the alternating currents that are flowing in the conductor at that instant.

FIG. 87.



Variation of current in the conductor *a* during one revolution.



Variation of current in the conductor *b* during one revolution.

The armature reaction due to the direct current is shown in Fig. 86 and has a value per pair of poles of

$\frac{1}{2} Z \times \frac{1}{2} I_{dc} = 0.25\ Z\ I_{dc}$ ampère-turns

Where Z is the total number of armature conductors.

The armature reaction due to the alternating current has a value per pair of poles of

$\frac{1}{3} Z \times I_{max} = 0.22\ Z\ I_{dc}$ from Fig. 84

$\frac{1}{3} Z \times 0.866\ I_{max} = 0.19\ Z\ I_{dc}$ from Fig. 85

so that the resultant armature reaction varies during $^1/_{12}$ of a cycle between 0.03 $Z\ I_{dc}$ and 0.06 $Z\ I_{dc}$ ampère-turns per pair of poles, or between 12 and 24 per cent. of the armature reaction due to the direct current acting alone.

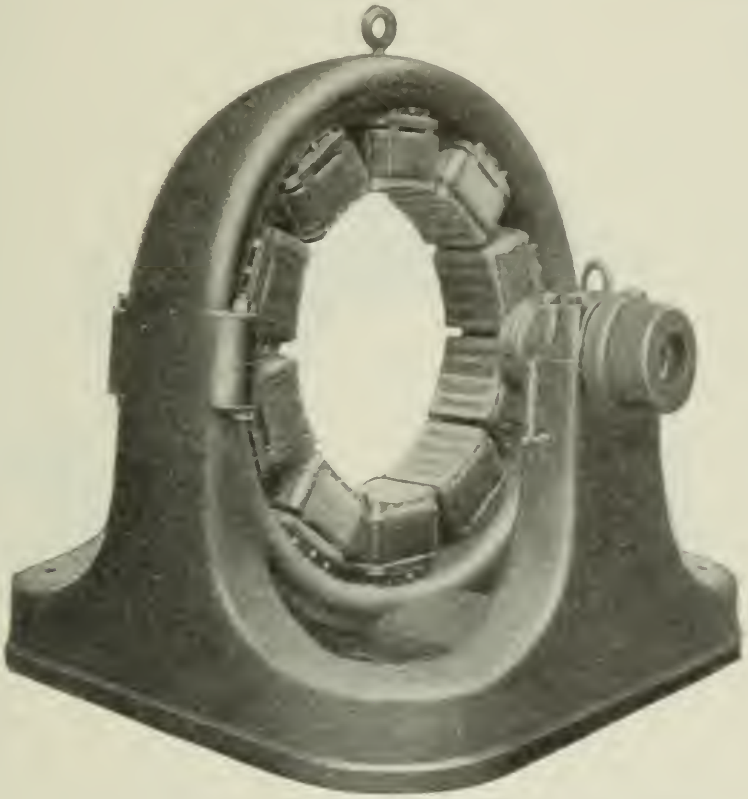
Armature Heating.—The variation of the current in the armature conductors during one revolution may be found as follows: The direct current in conductors *a* and *b*, Fig. 84, reverses as these conductors pass under the brush, while the alternating current in these conductors is the same at any instant and has its maximum value when the winding is in the position shown in Fig. 84. These two currents are plotted in Fig. 87 and the resultant current obtained by finding the sum of the two components at each instant. The loss in the conductors is proportional to the average value of the square of the resultant current, and is greater in conductor *b* than in conductor *a*, but in both conductors is less than would be caused by the direct current alone. The effect of reducing the power factor of the converter is to increase the alternating current for a given direct current and also to change their phase relation so that they do not neutralize so closely. The relative loss in the conductors for different power factors and for different polyphase connections is given in the table below.

Number of collector rings	Relative armature copper loss			Relative loss in conductors next the taps		
	Power factor, 100 per cent.	Power factor, 98.5 per cent.	Power factor, 94 per cent.	Power factor, 100 per cent.	Power factor, 98.5 per cent.	Power factor, 94 per cent.
Direct Current	1.0	1.0	1.0	1.0	1.0	1.0
3	0.587	0.627	0.753	1.249	1.594	2.048
6	0.274	0.304	0.400	0.430	0.614	0.874
12	0.209	0.236	0.326	0.249	0.354	0.525

The above table shows why rotary converters are operated at about 100 per cent. power factor and are not used, as are synchronous motors, for power factor control of circuits. It also shows the advantage of a large number of phases; few rotaries above 250-kilowatt output have less than six phases, while twelve phases have been considered for larger machines.

Troubles in Rotary Converters.—The rotary converter is subject to the troubles of both the synchronous motor and the direct-current generator. One of the first troubles encountered was hunting. This was cured by the addition of dampers to the pole face. One of the first type to be used was the cast grid damper shown in Fig. 88, and this has gradually been improved upon until now the usual practice is to put a squirrel-cage winding on the pole faces, as shown in Fig. 89, which winding, as in the case of the squirrel-cage induction motor, causes a restoring torque to be developed as soon as the armature speed varies from synchronism, which it does when the machine is hunting.

Fig. 88.



Rotary converter field, showing copper dampers on poles.

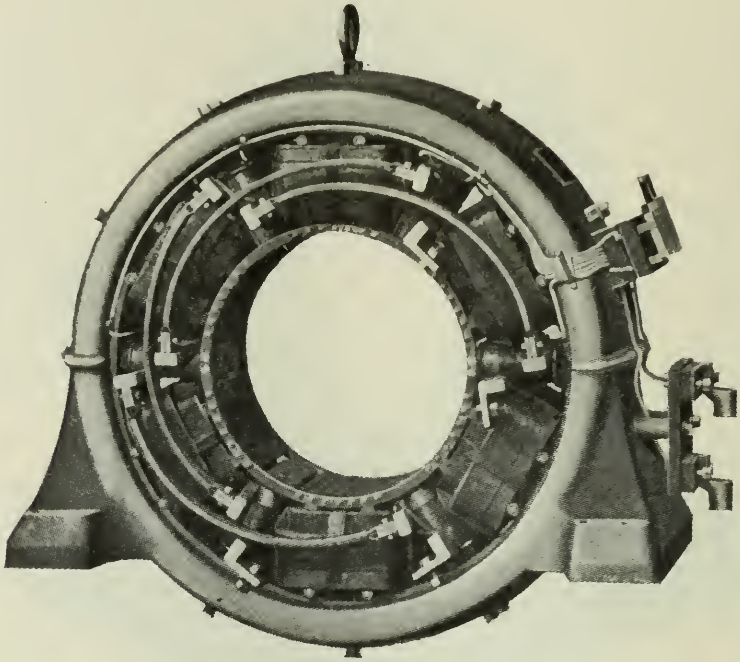
The problem of hunting having been solved, that of commutation now received additional attention, and as the rotary converter designs were worked up by men familiar with direct-current practice, it is not surprising to find that the development of the direct-current generator was paralleled by the development of the rotary converter, and that interpoles began to come into general use in 1909 and the speeds for a given output to increase.

In the case of the motor-generator set, where there is no restriction to the speed except that the operation shall be satisfactory and the cost a minimum, the gradual increase in speed is indicated by the following figures:

Date	Poles	Kilowatts	Revolutions per minute
1906	10	1000	514
1910	8	1000	750
1916	6	1000	900

The maximum speed for a direct-current machine of a given output is limited by sparking, and the sparking limit may be raised by the addition of interpoles. The speed is also limited by the tendency of the machine to flash over when the average voltage between adjacent commutator segments becomes too high, and the flash-over limit may be raised by the addition of a compensating winding. Certain assumptions being made, Fig. 90, which is a reproduction of Fig. 26, shows the highest safe speed at which a given output may be obtained.

FIG 89

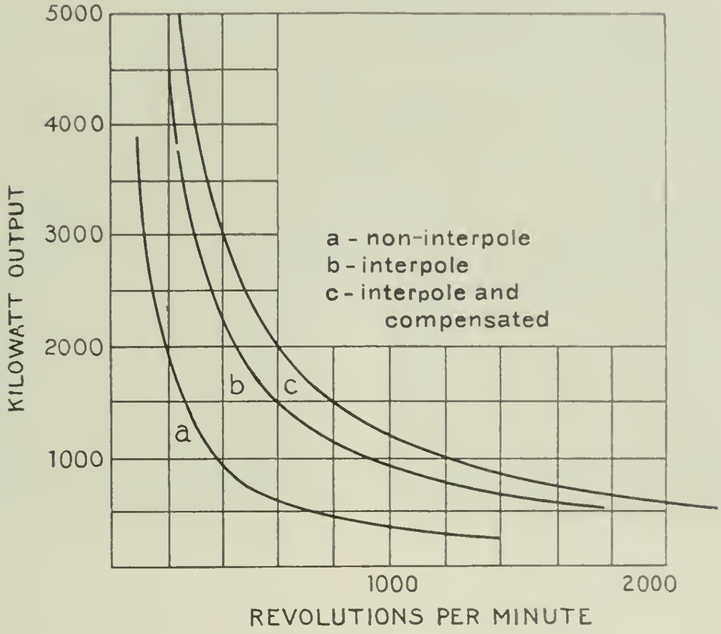


Rotary converter field, showing squirrel cage.

The non-interpole rotary converter has the advantage over the corresponding direct-current generator that the armature reaction is very small, so that the commutating field under the pole tip is not weakened with increase of load; one would therefore expect that the speeds of the non-interpole converters of 1909 would not be lower than those given by curve *a*, Fig. 90, and that interpole converters could be built for the speeds given by curve *b*. That this is indeed the case may be seen from the following table:

Kilowatts	Revolutions per minute in 1909	Revolutions per minute in 1917
500	500 at 25 cycles	
	600 at 60 cycles	
1000	375 at 25 cycles	900
	360 at 60 cycles	
1500	250	600
2000	187	
2500		400
4000		214
5800		225

FIG. 90.



Maximum output of direct-current generators.

The addition of interpoles has therefore caused a large increase in the speed and a corresponding decrease in the dimensions and in the cost of rotary converters.[27]

It must be noted, however, that, for a given frequency, the number of poles must decrease as the speed is increased, so that there are not so many sets of brushes at which to collect the current; therefore, as shown in Fig. 91, the commutators tend to become large relative to the rest of the machine.

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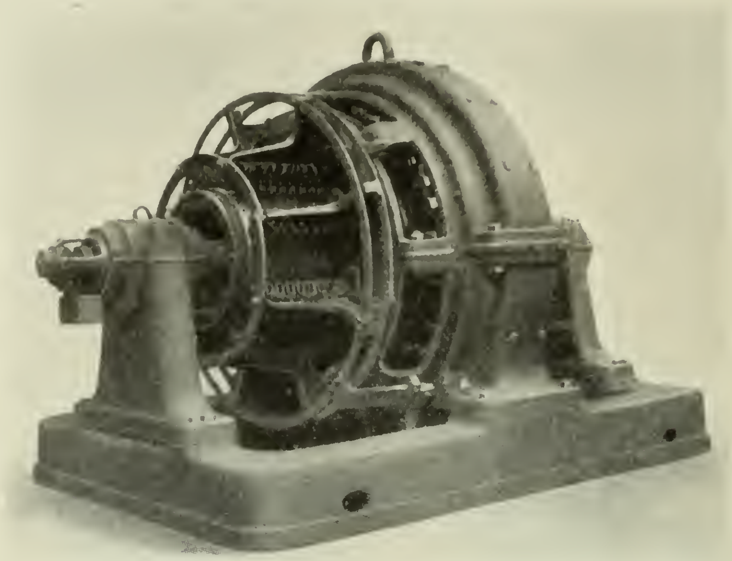
[27] "High-speed Rotary Converters," by McK. Yardley, *Electric Journal* vol. 11, p. 562.

It is largely because of this fixed relation between frequency, speed, and number of poles that sixty-cycle converters are more difficult to design and build than are those for twenty-five cycles;[28] there are so many sets of brushes that, as shown in Fig. 92, they are crowded together and the machine is liable to flash over. The distance between adjacent sets of brushes can be increased only by an increase in the peripheral velocity of the commutator, thus:

FIG. 91.



1000-kilowatt, 600-volt, 60-cycle, commutating-pole rotary converter. Modern type.

$$\text{frequency} = \frac{\text{poles}}{2} \times \frac{\text{R.p.m}}{60}$$

$$= \frac{\pi D x \text{R.p.m.}}{12} \; \frac{\text{poles}}{\pi D} \; \frac{1}{10}$$

$$= 0.1 \left(\frac{\text{commutator velocity in feet per minute}}{\text{distance between brushes in inches}} \right)$$

Up until 1909 it was not considered good practice to build commutators to operate with a peripheral velocity in excess of 4000 feet per minute, so that the distance between adjacent brushes of a sixty-cycle converter was limited to about 6.7 inches, the neutral zone was narrow, and, as shown in Fig. 92, there were many sets of brushes to be adjusted. If the minimum width of

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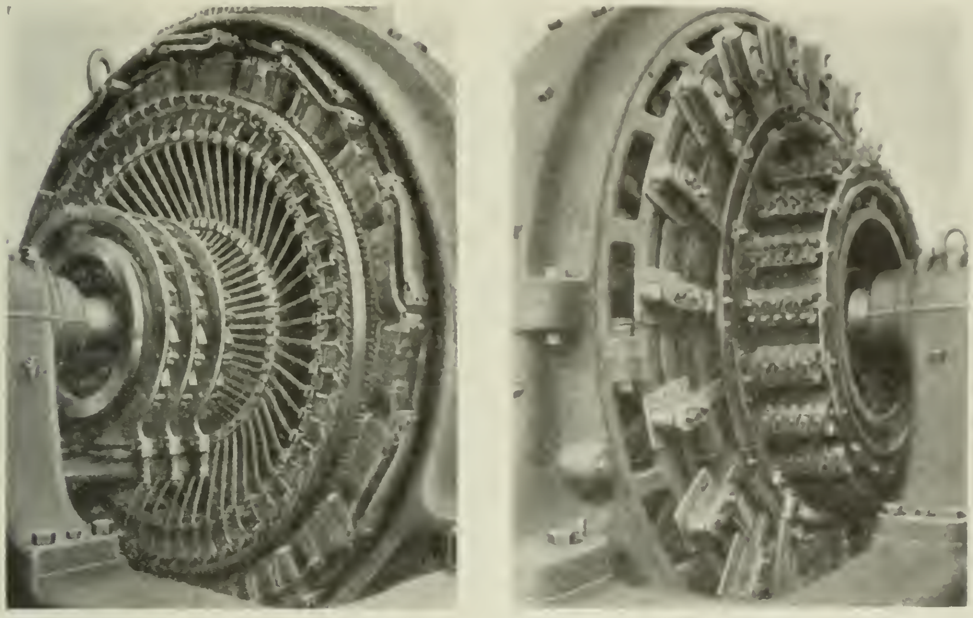
[28] "Sixty-cycle Rotary Converters," by Lamme, *Electric Journal*, vol. 13, p. 1124.

segment and mica of such a commutator is limited to $^{3}/_{16}$ inch, then the number of segments per pole cannot exceed 36, nor can the average voltage between adjacent commutator segments be less than 16.7 for a 600-volt machine. This value is rather close to the flash-over limit, particularly if the resultant armature reaction is such that the main field is distorted, as is the case when the machine is operating at power factors other than 100 per cent., and also when it is hunting. Improvements in the design of high-speed commutators, as for example the use of the three V-rings shown in Fig. 93, also improvements in the methods of constructing and seasoning of commutators, have made it possible to increase the peripheral velocity to 5400 feet per minute and to increase the distance between adjacent sets of brushes to 9 inches, so that it is now possible to use 48 segments per pole. There is the further advantage that the width of the neutral zone is increased 20 per cent., and the machine, therefore, is not so sensitive to slight inaccuracy in the setting of the brushes.

FIG. 92.

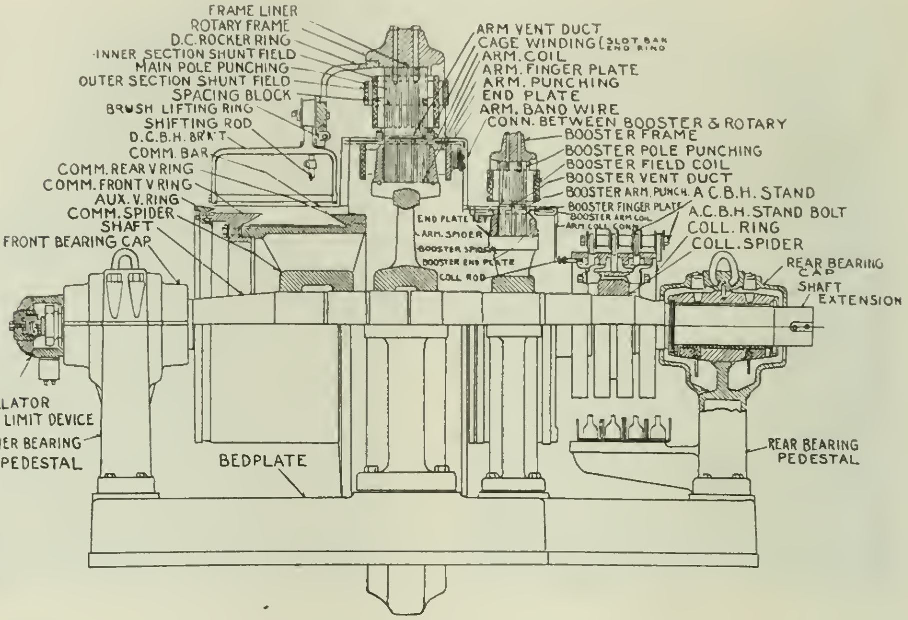


Alternating-current side of rotary converter, 1000 kilowatt, 600 volts, direct current, 60 cycles, six-phase.

Direct-current side of rotary converter, 1000 kilowatt, 600 volts, direct current, 60 cycles.

Interpole Design.—In a direct-current machine, the interpole excitation must be large enough to overcome the armature reaction and also to produce the desired commutating field, it therefore has a value of about 1.25 times the armature ampère-turns per pole; if, however, the machine carries a compensating winding on the pole face to neutralize the armature reaction, the interpole excitation will have a value of only about 0.25 times the armature ampère-turns per pole. In the case of the rotary converter the armature reaction is not zero; it is pulsating and has an average value of about 15 per cent. of the direct-current armature reaction, so that, in order to produce the desired commutating field, an interpole excitation of about 0.4 times the armature ampère-turns per pole is required.

FIG. 93.



Cross-section of a synchronous booster rotary converter.

It has already been pointed out in the section on direct-current machines that, due to interpole saturation, the commutating field is not directly proportional to the load current, and that the overload capacity of the machine is thereby limited. In the case of machines such as rolling-mill motors, which are subject to large overloads, it is necessary to prevent saturation of the interpole core, and this, we saw, was accomplished by the use of the pole-face compensating winding. So far as overload capacity is concerned, the rotary converter does not differ greatly from the compensated direct-current machine.

In at least two respects the problem of commutation is more difficult in the case of the rotary converter than in the case of the direct-current machine. In the first place, the armature reaction is pulsating and tends to cause pulsation of the interpole field. Commutation is also impaired by the hunting of the machine, because then there is a pulsation of energy superimposed on the normal condition of operation. The machine is running alternately above and below synchronous speed; while it is accelerating, kinetic energy is being stored in the revolving system, and while decelerating, this energy is given back to the line. The alternating-current armature reaction due to this effect is, first, that of a motor and then that of a generator, and so adds an alternating component to the interpole field.

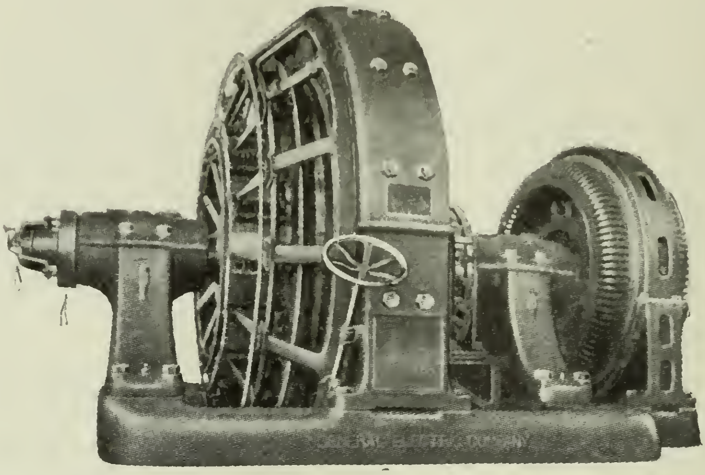
Both of these pulsating fields can be eliminated if a short-circuited turn is placed around the interpole, and this result is accomplished by the use of a complete squirrel cage for a damper. The squirrel cage, in addition, is more effective in preventing hunting than is the grid on the pole face. The use of such a short-circuited turn around the interpole has been avoided in direct-current machines because it prevented the interpole flux from responding instantly to large and sudden changes in load, but experience has shown that, in the case of the rotary converter, it is of greater importance to minimize hunting and to dampen out the oscillations of the interpole flux.

Brush Lifting.—Most rotary converters are started as induction motors from the alternating-current side. When voltage is applied to the armature a gliding field is produced which moves at synchronous speed relative to the armature surface. This field causes a large current to flow in the turns that are short-circuited by the brushes, and the interruption of this current when the armature begins to rotate causes destructive sparking. This sparking has become serious now that interpoles have been added, since they greatly reduce the reluctance of the path of that part of the flux by which the short-circuited coils are cut; it has therefore been found necessary to raise the brushes from the commutator when interpole rotary converters are started from the alternating-current side.

Protection Against Short-Circuits.—When the direct-current side of a rotary converter is short-circuited, there is a large rush of current which causes bad sparking and invariably causes the machine to flash over. Various baffles of moulded asbestos have been devised to smother the arc and prevent it from burning the armature winding and the brush rigging, but a more promising scheme is to open the circuit before the current has time to grow to a value large enough to start the trouble. A circuit breaker has been devised which will introduce a resistance into the leads within 0.005 second after the short-circuit has taken place and will then disconnect the machine from the line.

Voltage Control.—The rotary converter is essentially a constant ratio machine, but it is often desired to control the voltage of the direct-current side, the alternating applied voltage being constant. Three methods have been used for this purpose. The first to come into general use was the addition of a polyphase induction regulator to the alternating-current side of the converter, by means of which the voltage at the converter terminals could be varied above or below that of the line. This method is still used for the control of small machines. Two other methods were put on the market about 1908; namely, the split-pole converter [29] and the booster converter, but, because of certain difficulties in the addition of interpoles to the former machine, it has gradually given way to the latter. The booster converter consists of an alternating-current generator and a rotary converter with the same number of poles, both mounted on the same shaft. The generator may be of the rotating armature type as shown in Fig. 93, or, if this would require the use of too long and flexible

FIG. 94.



2000-kilowatt, 180 r. p. m., 700-volt, synchronous converter with revolving field alternating-current booster.

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[29] "Modern Types of Synchronous Converters," by Burnham, *General Electric Review*, vol. 15, p. 74.

a shaft, the rotating field type shown in Fig. 94 may be used. The voltage variation generally required is 15 per cent. above and below the average voltage for which the converter was designed, and this is accomplished by the use of a generator which has a capacity of only 15 per cent. of that of the converter itself. Since this output is comparatively small, there is no reason why the boosting generator should not be run at a much higher speed than that of the converter, except that in such a case the booster would have to form part of a synchronous motor generator set; this construction, however, has been used.

With the addition of the booster a new problem of interpole design was introduced. When the booster field is excited so that the booster voltage is added to that of the line, the booster acts as a generator and must therefore be driven mechanically by the converter acting as a synchronous motor, so that the alternating current in the converter is greater than that which corresponds to the direct-current output; there is therefore a motor armature reaction in addition to the normal reaction that exists due to the converter action of the machine, and this additional reaction is approximately proportional to the per cent. by which the voltage is boosted. When, on the other hand, the booster field is reversed so that the booster voltage opposes that of the line, the booster acts as a motor and delivers mechanical power to the converter shaft; the alternating current in the converter armature is then less than that which corresponds to the direct-current output; there is therefore a generator armature reaction in addition to the normal reaction due to the converter action of the machine. The interpole excitation must therefore consist of two parts—that which it would have if the booster were removed, and an additional excitation which is proportional to the booster voltage.[30]

Much more might have been written on the subject of modern rotary converters, alternators, and direct-current machines, and many other types might have been discussed, but this would have carried us beyond the scope of a series of articles that were written primarily for those central station engineers who are interested in what has already been done to obtain the maximum output from a given weight of material, and in what the prospects are for still further reductions.

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[30] "Synchronous Booster Rotary Converters," by McK. Yardley, *Electric Journal,* vol. 11, p. 267.

Catalysis. D. W. HORN. (*Transactions of the Wagner Free Institute of Philadelphia*, vol. viii, p. 97, July, 1917.)—Contact underlies chemistry. Bodies may influence each other at almost incredible distances, but this action is physical, not chemical. Briefly, no contact, no chemical action. In the time-honored generalizations of chemistry, its "fundamental laws," the action of pure substances upon each other was considered without reference to the effects of adjacent bodies. In some few instances, however, the effects of adjacent bodies were so striking as to compel early attention. Until recent years the multiplication of such instances has been slow. Such action or influence of an adjacent body may be covered by the term "catalysis," introduced by Berzelius, the famous Swedish chemist, in 1834.

In 1836 Berzelius compiled all cases known in which, by the presence of a foreign body, a chemical reaction is hastened without the foreign body itself being changed. These foreign bodies thus acting he called "catalysts." Historically, catalysis is not a new phenomenon. Processes of fermentation were known to the ancients, and these involve catalysts. In fermentation by yeast, the yeast plant produces the catalyst, or enzyme, as it is more frequently called. In sharp contrast with chemical reactions that, when not catalyzed, proceed at so slow a rate as to produce less than noticeable amounts of products stand the reactions that are so rapid as to be practically instantaneous. Reactions between ions are, for example, practically instantaneous. Catalysis, of course, is not concerned with such reactions.

It is not strictly true that a catalyst is found to be *unchanged* at the end of a catalyzed reaction. It is correct to say that the final products are the same as they would have been had the catalyst been absent. The catalyst may be rather unmistakably changed, not in amount, but in physical state. Thus the crystalline manganese dioxide used to generate oxygen from potassium chlorate becomes a fine powder, and changes in physical state are known to occur in iron oxide and in platinum used as catalysts in other systems. The amount of the catalyst, no matter how small, seems to remain unchanged. Catalysts themselves may be accelerated or restrained in their rapidity of action. Two catalysts usually have a greater joint effect than either would have singly. "Promoters" that increase the activity of catalysts are also known. Some substances so completely obstruct the action of catalysts that they have been called "poisons." Enzymes and toxins have their poisons and antitoxins, and the analogy to them is quite close, even in the case of metallic catalysts. Some catalysts seem specific for a given reaction, but many are capable of manifold application, and no general method is known for guidance in selecting a catalyst for a given reaction.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

TYPICAL CASES OF THE DETERIORATION OF MUNTZ METAL (60-40 BRASS) BY SELECTIVE CORROSION.[1]

[ABSTRACT.]

Brass of the type 60 copper and 40 zinc, which is used commercially in a variety of forms (*e.g.*, wrought bolts, sheathing, condenser tubes, extruded forms, etc.), often shows a kind of deterioration by which the metal changes its color to copper red and becomes very weak and brittle, although the shape and size apparently remain unchanged. This change of properties is due to a selective corrosion of the alloy, which has a duplex structure, when exposed to the action of some electrolyte, particularly sea-water. This type of corrosion has been recognized by manufacturers and users of brass for some time; the numerous samples illustrating this kind of deterioration which have been submitted to the Bureau of Standards, however, showed the utility of a description of typical cases of such corroded brasses. The study of such types includes bolts, boat sheathing, condenser tubes, and parts which were corroded while under stress.

The examination of the micro-structure shows clearly the method of the attack, the zinc-rich constituent being electrolytically "leached out," leaving a skeleton of weak pulverulent copper in its place, so that the piece becomes very weak and brittle. Later the second constituent may be attacked, so that the whole specimen is converted into pulverulent "copper"—the sample becoming so weak that it can be broken into fragments in the fingers.

Conditions which appear, from the examination of corroded samples, to accelerate this type of corrosive attack are: the micro-structural composition of the alloy, contact with strongly electronegative metals, the effect of certain adhering deposits of basic zinc chloride resulting from the corrosion, the thoroughness of the annealing the sample has previously received, the temperature of the electrolyte, and the stresses to which the specimens are subjected during the corrosive attack.

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* Communicated by the Director.

[1] Technologic Paper No. 103.

AN INVESTIGATION OF THE AXIAL ABERRATIONS OF LENSES.[2]

[ABSTRACT.]

THE errors which affect the definition of a lens are discussed, and methods of graphically representing the central errors described. The condition for freedom from coma near the axis is arrived at. The relative importance of the errors in different types of lenses is discussed. Hartman's method is expanded, permitting one set of measurements to give all the important central errors—spherical aberration, zonal variation of equivalent focal length, axial and oblique achromatism. The apparatus and procedure are described, and the accuracy of the adjustments and the measurements discussed. The method is applicable to all systems of relatively short focus and large aperture, such as photographic lenses, projection lenses, and telescope objectives, and also to complete optical systems. The results of the method as applied to a complete telescope are discussed and shown to be independent of the accommodation of the observer. Seventeen sets of curves are given for as many different lenses, and an illustrative discussion of one set of curves, together with a general description of the types of lenses represented by each group of curves.

SOME ELECTRICAL PROPERTIES OF SILVER SULPHIDE.[3]

By George W. Vinal, Assistant Physicist.

[ABSTRACT.]

SILVER sulphide may be prepared in the form of short wires or thin strips like a metal. The wire, which must be drawn hot, was found to conduct electricity like a metal of high specific resistance and practically zero temperature coefficient. The strip of sulphide rolled at room temperature has a large temperature coefficient and shows both metallic and electrolytic conduction. It has a volt-ampère curve characteristic of a pyroelectric conductor. The strips are sensitive to small alternating currents, which increase the resistance enormously, while small direct currents have the opposite effect. The specific resistance has been measured and experiments made on the electrochemical decomposition.

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[2] Scientific Paper No. 311.

[3] Scientific Paper No. 310.

THE EFFECT OF THE SIZE OF GROG IN FIRE-CLAY BODIES.[4]

[ABSTRACT.]

THE size of grain has long been known to exert considerable influence upon the properties of mortars, concrete, fire-clay refractories, and other materials. The present investigation determines the effect of the size of the calcined portion, or grog, upon the properties of fire-clay bodies within a field of practical sizes. The general plan of procedure consisted of separating grog into a number of sizes, recombining these in arbitrary proportions by calculation from triaxial diagrams, mixing with an equal weight of clay, and moulding with water into test pieces for the determination of various properties. Strength in the raw state, as indicated by the modulus of rupture, depended upon a number of factors and did not vary directly with the size of grog. Proper proportioning of grog sizes gave stronger bodies than single grog sizes. The strength of burned bodies increased directly with decrease of the size of grog, the size being expressed numerically as a surface factor. Bodies containing the larger sizes were more resistant to sudden heating and cooling from 600° C. and 1000° C. Volume shrinkage in burning to cone 12 increased approximately with decrease of porosity. No relation was found between strength and porosity in the dry or burned states. Methods are suggested for proper proportioning of grog for glass pots, saggers, and similar bodies.

WAVE-LENGTH MEASUREMENTS IN SPECTRA FROM 5600 A. TO 9600 A.[5]

By W. F. Meggers.

[ABSTRACT.]

SOME work in spectroscopic analysis at the Bureau of Standards showed the importance of investigating the red and adjacent infra-red regions of spectra more carefully and extensively. Ordinary photographic plates were stained in a mixture of dicyanin, water, alcohol, and ammonia to make them sensitive to

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[4] Technologic Paper No. 104.

[5] Scientific Paper No. 309.

the long light-waves. These stained plates were used to photograph the arc spectra of twenty of the chemical elements, including the alkali metals, the alkaline earths, and elements commonly found in iron as impurities. The photographs were made in the first order spectrum with a concave grating of 640 cm. radius, the grating being mounted in parallel light. This spectrograph gives a dispersion of about 10 Å. per mm. in the first order. With this apparatus exposure times of 30 minutes sufficed to record waves longer than 9000 Å. (Å = Ångstrom = 0.0000001 mm.), and demonstrated the value of dicyanin as a photographic sensitizer for such spectral investigations. Waves which are 2000 Å. longer than the longest waves in the visible spectrum were thus detected photographically without difficulty.

Accurate measurements of wave-lengths and determinations of the characteristics of the emission lines were obtained from these spectrograms. The second-order spectrum of the iron arc was photographed on either side of the first order, and the long wave-lengths were obtained from the standards in the iron spectrum. In this paper the wave-lengths in International Ångstroms are given for the arc spectra of the following elements: lithium, sodium, potassium, rubidium, cæsium, copper, calcium, strontium, barium, and magnesium.

Frequency differences of doublets in the spectra of sodium, potassium, rubidium, cæsium, and copper are shown by these wave-length measurements to be constant in most cases to one part in 100,000 in the number of waves per centimetre.

Comparison of the spectra made it possible to detect many impurities in the elements used for light-sources. Still more extensive spectral investigations are required in the region of long wave-lengths to identify all lines correctly.

THE FRANKLIN INSTITUTE

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of the Stated Meeting held Wednesday, September 5, 1917.*)

Hall of The Franklin Institute,
Philadelphia, September 5, 1917.

Vice-President Mr. Louis E. Levy *in the Chair.*

The following report was presented for first reading:

No. 2702.—Austin Organ.

The following report was presented for final action:

No. 2694.—Lewis Machine Gun.

Recommended that the Elliott Cresson Medal be awarded to Col. Isaac Newton Lewis, of Montclair, N. J., for his invention of the Lewis Machine Gun.

Geo. A. Hoadley,
Acting Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, September 12, 1917.*)

LIFE.

Mr. A. Atwater Kent, Manufacturer, Rosemont, Pa.

RESIDENT.

Mr. Frederick M. Bennett, Mechanical and Electrical Engineer, 112 West Pomona Street, Philadelphia, Pa.

Dr. George L. Kelley, Research Chemist, Midvale Steel Company, Philadelphia, Pa.

NON-RESIDENT.

Mr. P. F. Smith, Jr., General Superintendent of Motive Power, Pennsylvania Lines West of Pittsburgh, Pennsylvania Station, Pittsburgh, Pa.

ASSOCIATE.

Mr. Alan I. Appelbaum, Chemist, Import and By-Products Company, Trenton, N. J.

Mr. Carl D. Ulmer, Chemist, 408 Mellon Institute, Pittsburgh, Pa.

NECROLOGY.

Alois von Isakovics was born at Prague, Bohemia, on July 21, 1870, and died at Monticello, N. Y., on June 5, 1917. He was educated in Austria and graduated from the School of Chemistry of the University of Vienna.

In 1886 he came to the United States, and three years later established, in New York City, the widely-known Synfleur Scientific Laboratories for the synthetic production of perfumes. In 1903 the plant was removed to Monticello, N. Y.

Mr. Isakovics's occasional contributions to the technical press on subjects relating to perfumes, essential oils, and flavoring materials were read with interest by those engaged in similar fields of investigation and labor.

He was a member of the leading technical societies of the world, and his membership in The Franklin Institute dates from October 11, 1909.

Major Henry Souther, head of Aircraft Engineering Division, Signal Office, U. S. Army, died at the post hospital, Fort Monroe, on August 15.

He was born in Boston, Mass., on September 11, 1865. His early education was obtained in his native city, and his engineering training at the Massachusetts Institute of Technology, where he graduated in 1887.

Major Souther was engineer for the Pennsylvania Steel Company from 1888 to 1893, and the six years following he spent with the Pope Manufacturing Company, at Hartford, Conn.

He was president of the Souther Engineering Company, vice-president of the Standard Roller Bearing Company and of the Ferro Machine and Foundry Company. From 1899 to 1907 he served as Water Commissioner of Hartford, Conn.

Major Souther was called to Washington as consulting engineer of the Aviation Section of the Signal Corps in April, 1916, where he organized the inspection department. He was Director of the Langley Field, and conducted experimental tests of machines and engines. Major Souther was a member of numerous engineering and technical societies as well as social organizations.

The manuscript for his paper on "The Development and Progress in Aviation Motors," which appears in this issue, was finished only a short time before his last illness.

Mr. Virgil C. Bogue, 26 Courtlandt Street, New York City, N. Y.
Mr. R. S. Orr, Duquesne Light Company, Pittsburgh, Pa.
Mr. William F. Read, 209 Chestnut Street, Philadelphia, Pa.
Mr. Edwin Davis Tucker, 308 West 104th Street, New York City, N. Y.

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BOOK NOTICES.

Explosives: Their Manufacture, Tests, Properties, and History, by Arthur Marshall, A.C.G.I., F.I.C., F.C.S., Chemical Inspector, Indian Ordnance Department. Second edition. Philadelphia, P. Blakiston's Son & Company. 776 pages (total), contents and indices, illustrations, and several portrait plates. 2 volumes, large 8vo. Price, $16 net.

The early exhausting of the first edition of this work testifies to its excellence, a fact that we had occasion to note in the review of that edition. The enlargement has necessitated division into two volumes, which makes the book cumbersome, especially as heavy, coated paper is used, as was done in the first edition. There is really no necessity for such paper, which adds so much to the cost and weight of the book. Most of the illustrations could have been satisfactorily printed on lighter paper; moreover, many of them are too big. For instance, the picture of a section of armor-piercing shell, on page 559, would have shown the details just as clearly if it had been one-third its present dimensions.

The work is dedicated to Lloyd-George, whose picture appears as a frontispiece to one of the volumes, and who is at present, apparently, the real ruler of the British Empire, for if ever there was a time in English history of which it can be said that the "King reigns but does not govern," that time is now.

The reviewer can but repeat the commendations given in the review of the first edition. Mr. Marshall's extended practical experience enables him to present this important subject in all its aspects.

It was noted in the former review that no information is given in regard to the flash-powders so largely used in photography. These are nearly all very high explosives and well worth the careful consideration of experts in this field. An examination of the files of the *British Journal of Photography* and of the *English Mechanic* will bring to light many details of this class of "pyrotechnics" which have been the cause of much loss of life and property. The present edition, also, does not make any allusion to them, although a good deal of information is given concerning ordinary fireworks.

It is unfortunate that no advance has been made towards a scientific nomenclature. The same old forms, such as "glycerine," "acetate of lime," appear throughout. These phases of British non-progressiveness distress very much the American allies.

The work contains but few typographic errors; the structural formula of one of the dinitronaphthalenes (page 269) seems to be wrong, as it is designated as the beta-form, yet both nitro-groups are in the alpha-position. The statement is possibly taken from Thorpe (Dic. App. Chem., iii, 584), but does not accord with the orientation given in the same volume, page 563.

Mr. Marshall's work stands, at present, as the best exposition in English of the subject on which it treats.

Henry Leffmann.

PUBLICATIONS RECEIVED.

Explosives, by Arthur Marshall. Second edition, vol. ii. Properties and Tests. 795 pages, illustrations, 8vo. Philadelphia, P. Blakiston's Son and Company, 1917. Price, $8.

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Konstant auftretende secundäre Maxima und Minima in dem jahrlichen Verlauf der meteorologischen Erscheinungen XI. von Dr. E. van Rijckevorsel: Special Abzug aus Koninklijk Nederlandisch Meteorologisch Instituut, No. 102. Mededeelingen en Verhandelingen 22. 76 pages, illustrations, plates, 8vo. Utrecht, Kemin & Zoon, 1917.

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CURRENT TOPICS

The Properties of Balsa Wood. R. C. Carpenter. (*The American Society of Refrigerating Engineers' Journal*, vol. 3, No. 6, p. 30, May, 1917.)—The laboratories of Sibley College of Mechanical Engineering, Cornell University, have made an extended investigation of the properties of balsa wood for the purpose of ascertaining its physical properties. The wood is exceedingly light and promises to have an extensive field of usefulness in connection with cold storage structures where heat insulation is important. It is a tropical wood growing principally in the states of central and South America.

The wood is remarkable: first, as to its lightness; second, as to its microscopical structure; third, for its absence of woody fibre; fourth, for its elasticity; and, fifth, for its heat-insulating qualities. So far as the investigation has disclosed, it is the lightest commercial useful wood known. It has also considerable structural strength, which makes it suitable for many uses. In general appearance balsa wood resembles basswood. Until recently, Missouri cork wood, weighing 18.1 pounds per cubic foot, was believed to be the lightest, but recent investigations indicate that balsa wood is much lighter, having a weight of 7.3 pounds per cubic foot. The ordinary commercial balsa wood is seldom perfectly dry, and, because of the moisture content, its weight has been found to be between 8 and 13 pounds per cubic foot.

The extreme lightness of this wood suggests its application as a buoyancy material in life-preservers and lifeboats. When, however, it was attempted to apply the wood practically, it was found to be of little value, because it absorbed water in great quantities and also because it soon rotted and also warped and checked when worked. After testing nearly every method that had been suggested, Colonel Marr's method of treating woods which had been recently patented was finally successful. In this method the wood is treated in a bath, of which the principal ingredient is paraffin, by a process which coats the interior cells without clogging up the porous system. The paraffin remains as a coating or varnish over the interior cell walls, preventing the absorption of moisture and the ill-effects as to change of volume and decay which would otherwise take place; it also prevents the bad effects of dry rot which follow the application of any surface treatment for preserving wood of the same type. The Marr process tends to drive out all water and make the wood waterproof: it also improves its quality of being readily worked with tools without material increase in weight. The treated balsa wood has been used extensively in the manufacture of life-preservers, fenders for lifeboats, and for structures requiring insulation from heat, as in the refrigerating compartments of vessels and ice-boxes.

Tendencies in Bridge Construction. ANON. (*Engineering News-Record*, vol. 78, No. 11, p. 541, June 14, 1917.)—In the last 20 years the live loading of railway bridges has continuously increased. Every few years an increase takes place in bridge loads, and as often the opinion is expressed that the limit has been reached within existing clearances, or with the best locomotives that can be designed or with the available kinds of car wheels. When the Pennsylvania Railroad's Type R locomotive was believed to be a maximum for bridges, the loading might have been E-30, or even less. Many of those bridges are being replaced now, but they were fully loaded up to design capacity as much as 15 years ago. To-day live loading is in the region of E-60, and for a special bridge of the Bessemer and Lake Erie Railroad over the Allegheny River the live loading is on a basis of E-75. This, however, is a special bridge and is indicative of the maximum increment in loading rather than of the general average.

The Bessemer bridge, like the big Metropolis structure, is built of silicon steel, the newcomer in the company of nickel steel *et al.* Their use, so far, has been little more than a necessity in special cases, long spans and the like; they have had no influence on ordinary bridges. Stronger carbon steel than that used at present means a harder material; and harder metal than 60,000-pound bridge steel means drilling in place of punching. Present shops, as they are laid out and equipped, cannot drill any large tonnage, and punching must be depended upon, with the alternative of delay, trouble, and undue cost. Naturally, punching entails the use of tough, ductile steel.

As to truss types, the last 15 or 20 years have brought about little change, except for gradual extension of all-riveted construction and the recent use of k-webbing. The present tendency is toward simplifying trusses—using longer panels, simpler arrangements of bracing, and, wherever possible, eliminating subwebbing. In bridges of ordinary span it was the practice, not long ago, to make short panels—even 15 to 18 feet—where to-day 30 to 32 and 34-foot panels or longer are adopted. Among the several reasons for this, one is the reduction of secondary stresses, but more prominent is the effect of manufacturing advance and progress in erection appliances.

The widespread use of concrete construction has not in general influenced steel design. It is only in the development of concrete-floor types that it has effected changes in design. In bridges for certain classes of service concrete floors have practically supplanted trough floors. This refers particularly to bridges over streets in grade-crossing elimination and such structures. On truss railroad bridges there is little tendency at present toward solid floors, perhaps 95 per cent. is of the old standard open-tie construction. With longer panels coming into use, and, above all, the high impact that is always considered nowadays, the floor steel is a much more important element of the total weight, but this has no present effect toward producing changes in truss design, though such an effect is bound to come in time.

With regard to the future development of continuous bridges, we have been going through a slow progression away from pin-connected design. Had the craze for pin bridges that prevailed a generation ago for a short period continued, we would not be ready for continuous spans; but, as it is, the present standard practice in truss details is entirely suited to continuous bridges, and at the same time we have outgrown any fears that may have existed formerly as to the certainty of stress calculations in continuous strucures. It was formerly believed that if the supports should settle even a trifle, the stresses would be very seriously changed. On that subject we have clearer notions nowadays. Every bridge engineer appreciates that, no matter how rigid a bridge, a long span is in fact quite flexible, and any minor settlement of a support, such as could occur in a normal case, would have only trifling influence on the stresses. Continuous bridges are surely going to be more used in the future.

Spontaneous Combustion. G. H. P. WALKER. (*National Fire Protection Association,* vol. ii, No. 1, p. 32, July, 1917.)—When we speak of spontaneous combustion we usually refer to that peculiar form wherein ignition takes place without evidence of the employment of any external agent. When ignition has taken place combustion follows the same laws, whether of spontaneous or other origin, and these laws always represent more or less complex chemical actions. Almost all chemical actions are attended with the liberation of considerable heat, and the quantity of heat set free is constant, whether the action be relatively slow, as in the decaying of a piece of wood, or whether it be rapid, as in the combustion of a similar piece of wood in a furnace, the products of combustion being identical in either case. Combustion, as we usually understand it, is the union of a substance with oxygen, but there are numerous instances where oxygen is not involved at all. The velocity of combustion increases with marvellous rapidity with rise of temperature, a rise of 200° F. increasing the velocity one thousand-fold.

Perhaps one of the commonest forms in which spontaneous combustion manifests itself is in the spontaneous ignition of a piece of cotton waste or an old rag saturated with oil and left lying in a warm place. Only certain oils possess the property of spontaneously igniting, and of these the most dangerous is linseed oil, the boiled variety being much worse than the raw, due to slight changes in its chemical structure which have been effected by the boiling, and due also to the presence of metallic salts (such as lead acetate, litharge, and manganese dioxide), which tend to accelerate the process of "drying" by acting as oxygen carriers. When spontaneous combustion results from an oil-soaked rag (or an oil mop, for instance) having been left carelessly in a warm room or in the sun, it is caused by the rapid oxidation of the oil spread out over the large surface afforded by the folds of the cloth—the greater the exposed surface the more rapid the oxidation—and as the oil continues to combine with more and more oxygen from the air, the temperature gradually rises until sufficient heat has been developed to cause the mass to burst into flames. Mineral oils are not considered dangerous in this respect, and are sometimes added to quick-drying oils to lessen the danger of spontaneous ignition.

The reason why a can of linseed oil does not ignite when left uncovered is that the small surface exposed to the air cannot develop heat with sufficient rapidity to raise the whole body to the required temperature. Many other forms of spontaneous ignition occur, such as the ignition of finely divided particles of combustible substances suspended in the air, the oxidation of iron pyrites in soft coal, the slow oxidation of heaps of organic matter, as manure and hay and others. In all of these the surface-volume conditions play the important part in governing the relation of heat generation and dissipation upon which depends the rise in temperature.

The Artificial Silk Industry. L. P. WILSON. (*Journal of the Society of Chemical Industry*, vol. xxxvi, No. 14, p. 817, July 31, 1917.)—The material known as artificial silk, and sometimes wrongly described as imitation silk, is now in such general use for producing a large number of textile materials that there is no doubt whatever that, although the commercial production of artificial filaments is no older than this century, it has made for itself a permanent position in the world of industry. Artificial silk, once only suitable for fancy goods, more ornamental than useful, is now produced in filaments of almost unlimited length, of uniform diameter, and of any thickness from less than a thousandth of to a sixteenth of an inch, possessing any desired lustre, from the most brilliant to quite dull, capable of being dyed to any shade, and of sufficient tenacity, either dry or wet, to be used in any textile operation.

There was a period of one hundred and fifty years between the time of the suggestion of the French scientist, Réaumur, that silk might be made artificially from resins or similar materials and the date of the first patent, that of the Swiss, Andemars, for the production of artificial filaments, this latter having been made possible by the discovery and investigation of cellulose nitrate. From that time, about 1885, to the end of the century, a great deal of valuable preliminary work was done with the aim of producing artificial fibres for textile use or the production of electric lamp filaments. Among the British workers of note were Crookes, Wynne, Powell, Swinbourne, Swan, Millar, Cross, Topham, and Stearn, but they did not achieve commercial production during this period. On the Continent, however, Compte Hilaire de Chardonnet began to manufacture artificial silk in 1891, at the rate of 100 pounds per day, at Besançon, and, although his success was not uninterrupted, he was producing about 4000 pounds per day before anything was made on an industrial scale by British workers.

All the early artificial silk was made by the Chardonnet process or modifications of it, which had for a basis gun-cotton dissolved in ether-alcohol. This solution was of very high viscosity and was formed into filaments by forcing it through glass jets with a bore between two and ten thousandths of an inch. These were immersed in water to remove the alcohol from the solution as it emerged, and so to form a solid fibre, which was picked up and with a number of others wound on a spool. On the Continent nitro silk had for some years great financial success, but at the beginning of this century it had to meet increased prices of raw materials and the competition of two other processes, cuprammonium and viscose.

The difficulties and defects of the processes of producing silk from nitro-cellulose led to much research after other methods and substances suitable for the production of artificial fibres, and the next process to be developed was that which made use of a solution of cellulose in ammoniacal copper oxide for spinning. A Frenchman, Despaissis, took out the first patent in this connection in 1890, but his early demise led to the lapsing of the patent until Pauly took out his first patent in Germany seven years later. Then followed a long series of patents which have been the basis of successful manufacture of the Vereinigte Glanzstoff Fabriken A. G. of Elberfeld, with subsidiaries in Austria, France, and Wales.

Viscose silk, the latest of the three important forms of artificial filaments to appear on the market in quantity, is the only one which is entirely English in its origin and development. Like the other artificial silks, it is a form of cellulose, but, unlike them, its starting material is not cotton but wood, and as it differs from them in its beginning, so it differs right through its stages of manufacture in processes and machinery, reactions and methods, until the final product is obtained. This also is distinguished from the others by its greater covering power and lustre, and its greater resistance to dyeing and finishing processes, and to wear. For these reasons it is thought by some competent to judge that, although its manufacture is more complicated than the older processes, it will ultimately supplant them. Cellulose xanthate, which forms the basis of the viscose silk process, was discovered by Cross, Bevan, and Beadle in 1892, and is formed by the interaction of cellulose, sodium, hydroxide, and carbon bisulphide. When dissolved in water or dilute caustic soda it forms a golden-brown thick syrup, and to this the discoverers gave the name viscose on account of its high viscosity.

The whole industrial history of artificial silk is embraced in the development of the nitro, cuprammonium, and viscose processes, but a number of other methods have been suggested and patented. The earliest, and at one time perhaps the most promising, because it was long successfully worked in the manufacture of electric lamp filaments, was the zinc chloride process; in spite of much work this has not been satisfactorily applied in the manufacture of artificial silk.

The Engineering Council. ANNOUNCEMENT. (I. N. Hollis and C. Townley, August, 1917.)—The formation of an Engineering Council is the outgrowth of a real need for proper consideration of questions of general interest to engineers and to the public, and to provide the means for united action upon questions of common concern. This war has brought out very impressively the actual need for united action of some kind. At present the Council is concerned with four societies, because that seemed the most practical way of getting a group of men together to answer immediate needs, but these societies do not assume to speak for all engineering societies in the country.

A now manifest need of enlargement may be effected by the union of all societies, either as the outgrowth of the present Council or by a congress of engineers leading to united action by all societies. We have three classes of engineers to reach: First, those who are members of local societies and not members of national societies; second, those who are members of national societies and not members of local societies; and, third, those who are not members of a society. The last-named class constitutes a very large number in our profession.

The four societies concerned at present are The American Society of Civil Engineers, The American Institute of Mining Engineers, The American Society of Mechanical Engineers, and The American Institute of Electrical Engineers. Many fruitful discussions have taken place leading to useful action, and many problems have already been presented before the Council. Certain questions, however, relate to the war and the assistance that engineers can render, and a committee, to be called the American Engineering Service Committee, was appointed with instructions to invite the coöperation of all engineering societies. Its present duty is the tabulation and listing of members of the five societies represented. This tabulation has already in part been done, but in a rather unsystematic and unequal way. It is hoped that the new committee, by having additions from other societies, may make a final and lasting tabulation of all the engineers in the United States. The list is to be kept in the Engineering Societies' Building for general use in government problems and in the industries. A great many engineers have already entered through the engineering societies, through colleges, and through various special boards in Washington. The importance, however, of a complete list of engineers and their professional specialties cannot be overestimated, and such a complete list can only be made with the help of the local as well as of the national societies.

The office of the Council will be in the Engineering Building, 29 West Thirty-ninth Street, New York City.

Effect of Gas Lighting upon Ventilation. ANON. (*American Gas Engineering Journal,* vol. cvii, No. 8, p. 171, August 25, 1917.)—The assertion that gas lighting vitiates the atmosphere is often made, not because of a desire to unjustly condemn gas for illumination, but because of a conviction that the use of gas produced an alteration of the atmosphere which is harmful. Ordinary air is chemically defined as a mixture of the gases oxygen and nitrogen in the proportion of 20.7 per cent. by volume of oxygen and 79.3 per cent. by volume of nitrogen. The oxygen argument is one of the weapons which has been actively employed in creating the impression that the use of gas so decreases the oxygen content of the atmosphere that life is endangered. It is only when the oxygen content of the atmosphere is lowered below the region of 15 per cent. that signs of insufficient oxygen arise. Such a small reduction as about 1.5 per cent. under the worst possible conditions of ventilation has not the slightest effect upon health or comfort.

The sense of well-being depends very greatly upon the condition of the skin, and its ability to perform its functions. If the percentage of water vapor in the atmosphere is high, the evaporation from the body is greatly checked, but if the air is sufficiently removed from the saturation point, the functions of the body proceed as they should and health is unimpaired. Much of our comfort then depends upon temperature and humidity. The thermometer, however, is of very limited value in determining the comfort of the body, because it does not show the cooling effect of moving air or the change in cutaneous excitations produced by the variation in the strength of air currents. For estimating the physical conditions of the atmosphere we need an instrument to measure the rate of heat lost and not the average temperature.

Popular Lecture on Home Lighting. (*Bulletin Illuminating Engineering Society,* August, 30, 1917.)—The second of a series of popular lectures issued by the Illuminating Engineering Society is now ready for distribution. This lecture is devoted to the application of the fundamentals of home illumination. Some forty-five lantern slides accompany the lecture, which covers in detail and in an authoritative manner the specific requirements for home-lighting installations, combining the scientific, artistic, and psychological principles, but stating these requirements in a non-technical paper of interest to popular audiences. The paper covers some twenty pages of reading matter and paragraphs descriptive of the lantern slides.

The lecture, with accompanying lantern slides, may be secured for presentation upon application to the general offices of the society, 29 West Thirty-ninth Street, New York City. Reservations should be made considerably in advance of the dates of presentation, as only a few sets of the lecture are available at this time. A small service charge covering the cost of upkeep and delivery is made for this lecture and for a similarly prepared lecture on " Store Lighting."

The Flow Meter and Its Relation to Plant Economy. J. H. HOUGH. (*General Electric Review*, vol. xx, No. 8, p. 649, August, 1917.)—The turbine and operating-rooms of the average power plant are provided with an up-to-date switchboard carrying every type of electrical instrument needful for the efficient distribution of power. By sharp contrast in the boiler-room, the fireman must struggle to hold the load on the boilers, with no guides to assist him but a pressure-gauge and a water column. The electric generators operating in parallel on the bus-bars are equipped with wattmeters to show exactly the load on each. The steam boilers operating in parallel on the main header are being operated blindly, with nothing to indicate in what manner they are dividing the load. The man who approves the coal bill does not stop to analyze the load efficiency curve of the boiler. He perhaps does not know that at one particular rating the best thermal efficiency is obtained, and that this efficiency drops rapidly when the boiler is very much below or above this point.

The big opportunity for reducing costs lies in the boiler-room. No one would expect the electrical end of the plant to be operated satisfactorily without some instruments to guide the operators. Yet the pressure-gauge and water column have been and are about all the average boiler attendant has to help him. For the rest, he is expected to be able to get along by using his eyes to judge the condition of the fire. There are some men naturally gifted who can do fairly well even under these circumstances, but the problem need not be left to human judgment when it can be easily simplified by providing a few thermometers, a steam flow meter, and a draft-gauge.

At the present time the flow meter finds its greatest field of usefulness on individual boiler units. It is the ammeter of the boiler. Various designs of the instrument have been brought out for this use, having its respective field of application. In one large plant the boilers are equipped with standardized indicating instruments to show the output of each unit at any instant in boiler horsepower. Changes of load affecting the efficiency are indicated and recorded, making it possible to govern the output of each boiler for the best efficiency.

Memorial to Joseph Priestley.—On July 31, 1874, many of the leading chemists of America met near the grave of Joseph Priestley, at Northumberland, to honor the memory of the man who had discovered oxygen one hundred years before. In an account of the proceedings detailed in the *American Chemist* for 1874 we are told that a movement was there begun which led later to the establishment of the American Chemical Society. As the foundation of the American Chemical Society has been thus linked with the name of Joseph Priestley, it would seem proper that his work as an investigator and philosopher and tireless searcher after truth should be commemorated in some lasting way.

To this end, the Council of the American Chemical Society adopted a resolution at its meeting in Urbana, in April, 1916, requesting the president to appoint a committee to devise and carry out a plan for a suitable memorial to Joseph Priestley. After careful consideration of various plans, the committee recommended: (1) That a bust portrait of Joseph Priestley be secured, to be a copy of the best available portrait; that this be retained as the property of the American Chemical Society, but be deposited as a loan to the National Museum in Washington. (2) That a gold medal be awarded at intervals of probably more than one year for superior achievement in chemical research; the award to carry with it the requirement that the recipient shall deliver an address before the general meeting of the society at the time of the presentation or at such other time and place as the Council may direct. Careful inquiry has convinced the committee that a fund of at least $2000 should be secured to carry out this plan. It is requested that subscriptions be sent to the chairman or any member of the committee. The committee is composed of fifteen members, of which Dr. F. C. Phillips, University of Pittsburgh, is chairman.

The United States Rifle, Model 1917. S. TRASK. (*Arms and the Man,* vol. lxii, No. 22, p. 429, August 25, 1917.)—Tried and tested, the performance of the new service rifle of the United States Army, officially designated "U. S. Rifle, Model 1917," has exceeded the most sanguine hopes of its sponsors. It is under this name that the British Enfield rifle of 1914 adapted to United States ammunition is known. Some apprehension was felt as to the trustworthiness of the new rifle, but fortunately the adaptation has now progressed to a point fully demonstrating that the change has been accomplished with due regard to the safety of those who will use the arm. The dimensions of the metal in the model of 1917 are equal to, and in some parts greater than, those in the Springfield. This strengthening has been principally over the receiver and at the butt of the barrel. In addition, the bolt of the new model is of nickel steel, and the receivers either of nickel or carbon steel. Facts of considerable interest concerning the model of 1917 and the arm from which it was adapted are gradually becoming known, and a statement from an officer who has given much time and study to the matter adds some illuminating details to the facts already known. He says:

"When the question of the desirability of obtaining a flatter trajectory with small arms was opened it was found that with the service 0.303 British rifle, known as the short Lee-Enfield, it was not possible to obtain as flat a trajectory as desirable, but a compromise was made and the Mark VII ammunition was introduced. This mark of ammunition differs from the Mark VI in the bullet having a sharper point and weighing 174 grains instead of 215 grains, the ballistics obtained in the short Lee-Enfield rifle being 2440 f/s. muzzle velocity with the cartridge heated to 60° for a maximum chamber pressure of 45,400 pounds per square inch. This ammunition gives a maximum height of trajectory of just under 9 feet for a range of 800 yards.

"It was obvious that the desired maximum height of trajectory of 5¼ feet for this range could not be obtained in the short Lee-Enfield rifle, and the question of the introduction of a new design of rifle was taken up. This led to the design of a rifle of 0.276 bore firing a rimless cartridge, and at the outbreak of the present war the trials had almost reached finality. One thousand of the rifles had been made and issued to troops for trial, and the design of the rifle was favorably reported upon. The ballistics given by this rifle were 2800 f/s. muzzle velocity for a chamber pressure of 51,500 pounds per square inch. The diameter of the base of the cartridge was 0.526 inch.

"When the war broke out, all question of re-arming had to be dropped. A large number of rifles, however, were required, and as no gauges for the short Lee-Enfield rifle were available, and as it was considered that the 0.276 rifle was of simpler design for manufacture and that re-arming would be taken up again at the conclusion of the war, some of the 0.276 rifles were sent to rifle manufacturers in this country to see if they could make rifles similar in design, but barrelled to take the British 0.303 Mark VII cartridge. This led to the introduction of the rifle magazine 0.303, Pattern 1914. This rifle only differs in design from the 0.276 rifle in the dimensions of the interior of the barrel, in the magazine arrangements, which had to be made suitable for a 'rimmed' cartridge, and the graduations of the sights.

"The diameter of the base of the Springfield cartridge being 0.473 inch against 0.526 inch, and the chamber pressure in the Springfield rifle with the cartridge of Model 1906 and in the 0.276 rifle being the same, it will be seen that the 0.276 rifle was designed to stand a greater thrust on the breech bolt and recoil surfaces than the Springfield rifle."

Immense Deposits of Potash Awaiting a Cheap Method of Extraction. ANON. (*U. S. Geological Survey Press Bulletin,* No. 333, September, 1917.)—The United States Geological Survey, Department of the Interior, has prepared a brief report on the deposits of greensand in the eastern part of the United States which contain potash. These deposits are immense beds of sand at or near the surface in New Jersey, Delaware, and other states on the Atlantic coast. They cover many square miles, are at some places as much as 30 feet thick, and carry locally a maximum of 7 per cent. of potash. The prospective value of these deposits at any place depends upon the quantity of greensand available and the ease with which it can be mined. Most of the deposits can be mined with a steam shovel or dredge.

Greensand usually consists of grains of glauconite, an insoluble silicate of potash, iron, and silica (which may contain 7 per cent. or more of potash), mixed with grains of quartz and other materials. It gradually decomposes on exposure to the weather, its potash being thus slowly rendered available for assimilation by plants. It has been used in the raw condition as fertilizer for over a hundred years, as much as 100,000 tons having been mined in a single year in New Jersey. However, though its use has proved profitable at places within easy hauling distance of the deposits, the freight rates prohibit a long haul of material containing so small a proportion of potash. The chemical and engineering problem is therefore to extract and concentrate the potash.

Experiments made by chemists and others give hope that some economical process of extraction will be found, and when a cheap process has been devised there will be an immediate demand for detailed information concerning the location, nature, and supply of greensand. In order to meet this expected demand the Survey has prepared this report.

According to the report, the best greensands are in New Jersey, running in a series of broad belts from Sandy Hook Bay southwestward across Monmouth, Ocean, Burlington, Camden, and Gloucester counties into Delaware, where they are abundant as far south as Middletown. Other less valuable deposits occur in Maryland, Virginia, North Carolina, Arkansas, and Texas, and probably other Southern States may contain similar deposits. The best of this sand will carry about 6.3 pounds of potash to the cubic foot, or about 75,000 tons for each square mile of sand one foot thick, or 1,500,000 tons for each square mile of a 20-foot bed. A bed of that thickness carrying 5 per cent. of potash should contain more than 1,000,000 tons of potash to the square mile and should also carry about 4,500,000 tons of iron and possibly 500,000 tons of phosphoric acid. To utilize these constituents is a problem in chemical engineering; to measure the raw material is the simpler problem in practical geology.

The paper also describes the methods of analysis of greensand, especially a new method worked out in connection with this study. It is published as United States Geological Survey Bulletin 660-B, "Notes on the Greensand Deposits of the Eastern United States," by George H. Ashley, and "Methods of Analysis of Greensand," by William B. Hicks and Reginald K. Bailey. The paper can be obtained free of charge by writing to the Director, United States Geological Survey, Washington, D. C.

Calcium Chloride. Anon. (*U. S. Geological Survey Press Bulletin*, No. 333, September, 1917.)—Calcium chloride is made from natural brines found in Michigan, Ohio, and West Virginia. As the same brines yield salt and bromine, practically every constituent in them is turned to profit. Calcium chloride is used as the circulating fluid in refrigerating plants, in cement concrete, and in automobile gas-engine water jackets to prevent freezing, and, on account of its power of absorbing moisture, for laying dust on roads, drying gases, vegetables and fruits, and dehydrating organic liquids. Calcium chloride in solution is especially valuable in automatic-sprinkler systems and in fire buckets.

According to the United States Geological Survey, Department of the Interior, the quantity of calcium chloride produced from natural brines and sold in the United States has recently been about 20,000 short tons a year, valued at $6 to $6.50 a ton. In 1916 the production from natural brines was 26,062 tons, valued at $216,729, the equivalent of $8.31 a ton.

Chromite, Important War Mineral. Anon. (*U. S. Geological Survey Press Bulletin*, No. 333, September, 1917.)—The importance of chromite as a war supply in the manufacture of armor plate, armor-piercing projectiles, stellite for high-speed tools, and automobile and other special steels can scarcely be overestimated, according to the United States Geological Survey, Department of the Interior.

The chief sources of supply for the United States during the last few years have been Rhodesia, New Caledonia, Turkey, and Greece, and the imports in 1916 were 114,655 long tons.

The greatly increased trade, especially in steel, and consequently larger demand for chromite have stimulated the search for it in the United States, as shown by the phenomenal increase in production, the amount sold in 1915 being only 255 tons, against more than 47,000 tons in 1916. In Maryland and Wyoming there has been only a small production, but in the Pacific coast states, especially California, the advance in the output has been remarkable. In Oregon the production was more than 3000 tons; in California it was nearly 44,000 tons. Not all of this was sold.

It is evident that for some time to come California will furnish the chief domestic supply. With a lively demand and good prices bodies of ore farther from lines of transportation will be worked. The production from some deposits in 1917 is expected to exceed that of 1916.

An interesting feature of future chrome production lies in the fact that T. W. Gruetter has recently established at Kerby, Ore., a custom plant for concentrating black sand to win its gold and platinum. The black sand of the Klamath Mountains usually contains a considerable amount of chromite, and it is believed that by adding magnetic separators to Gruetter's plant to remove the other minerals from the tailings sufficient chromite may be obtained from the black sand in areas of chromiferous serpentine to make the operation financially successful. The process will evidently yield a high grade of chrome ore, which may be suitable for special uses.

There is considerable chromite in Cuba, but scarcely anything is known of its occurrence in Mexico or Central and South America.

Ferrochrome, the alloy used in making chrome steel, is now manufactured in the United States by electro-metallurgic methods, almost wholly in the East, at the plants of the Electro Metallurgical Company at Niagara Falls and elsewhere. It is reported, however, that the Noble Electric Steel Company has three furnaces at Heroult, Calif., operating to their full capacity in producing manganese, chrome, and silica steels.

Prospecting for chromite may disclose other supplies, and the most profitable deposits will be those in areas of serpentine that are adjacent to cheap rail or water transportation or connected with it by good roads. Cheap concentration may in places improve the grade of the ore available for profitable mining.

With the known supplies of chromite and others whose discovery within the limit of practicable transportation throughout the United States is confidently expected, there is good reason to believe that the domestic output of chromite could be so increased as to go far toward supplying the domestic demand if our imports, except those from Canada, were cut off.

The Purple Color of Lamp Globes. M. LUCKIESH. (*General Electric Review,* vol. xx, No. 8, p. 671, August, 1917.)—The purplish tint of lamp globes is commonly observed. Glasses exposed to sunlight and to X-rays sometimes undergo a similar change. It is generally assumed that this color is due to a change in the chemical or physical state of the manganese which is present in most clear glasses. This coloration of glasses under exposure of radiant energy is not alone confined to glasses containing manganese. Sometimes glasses containing potash, but free from manganese, gradually assume a bluish tinge, and those containing sodium a yellowish-green tinge. Spectral analyses show conclusively that the purple coloring is due to manganese. This color is quite unstable, for it disappears under the moderate heat of the Bunsen flame long before the glass is sufficiently hot to lose its rigidity. Manganese in clear glass performs the primary function of neutralizing the greenish tint usually present owing to slight quantities of iron oxide in the ingredients of the mix.

The spectral transmission of a glass containing a slight amount of iron is approximately complementary to that of a glass containing a slight amount of manganese; that is, the purple of the manganese neutralizes the green of the iron. This, however, is done at the expense of light transmission. An example will make the process clear. Suppose the slight amount of iron present reduced the transmission factor by 5 per cent., and that in order to neutralize this color a sufficient amount of manganese must be incorporated to reduce the transmission factor by 6 per cent. Without considering surface reflection, the total transmission loss becomes 11 per cent., and the only return for this loss is a neutralization of the slightly greenish tint.

Besides this initial decrease there is often a gradual decrease in the transmission factor as the purple color is brought out by the intense radiation from the sun and artificial light sources. Measurements show that when this color is noticeable to casual observation the transmission factor has been reduced from 10 to 25 per cent. Pieces of arc lamp globes have shown transmission factors of slightly more than one-half, and other specimens in which the purple color was quite pronounced have shown a loss varying from 55 to 85 per cent. A remedy for such losses is to eliminate manganese and accept the greenish tint with its higher transmission factor.

Lamp with Renewable Filament. ANON. (*Electrical World*, vol. 70, No. 9, p. 410, September 1, 1917.)—An incandescent lamp which can be readily recharged with gas and fitted with a new filament is disclosed in patent No. 1,232,741, issued to A. J. West, of Winnipeg, Manitoba. In this lamp, which is of the gas-filled type, there is no need for a vacuum, as it is only necessary to retain the gas in the globe under its own pressure. Accordingly the lamp is so made that the globe can be removed to permit the renewal of the filament, and when the globe is attached to the head the joint is tight enough to retain the gas admitted. Further, in the head is provided an easy means for refilling the lamp with gas and retaining the gas.

Upon the filament being rendered useless the globe can readily be unscrewed from the head and the filament withdrawn through the neck of the globe. After a new filament has been substituted the globe can be replaced. At this time, however, it is necessary to recharge the globe with gas. This is done by removing a screw plug and recharging the globe with gas through a provided opening. Upon the globe being filled with the gas it is screwed tightly in and the plug is inserted.

Bibliography of the Literature of Submarines, Mines, and Torpedoes. D. B. RUSHMORE, W. H. LANMAN, and E. A. LOF. (*General Electric Review*, vol. xx, No. 8, August, 1917.)—At the present moment there is a widespread desire for knowledge on the subject of submarines, the information concerning which is widely separated and is difficult of location and access. Little has been known by the public in general on this subject, partly because of its apparent relative unimportance, and partly because much of the activities concerning these boats has been considered confidential and the subject somewhat shrouded in secrecy. The enormous losses sustained by the successful tactics of this type of craft have made the problem of finding a means of overcoming this menace paramount to all else.

With a view to making as accessible as possible available sources of information that may be of some assistance in solving this problem of the hour, a considerable effort has been made to gather in this issue of the *Review* a bibliography on submarines and allied subjects covering the period between 1873 and 1917. A list of patents on the same subjects dated from 1850 to the present is also given. Among the books mentioned, by far the best historical treatise to be had is the "Evolution of the Submarine Boat, Mine, and Torpedo," by Commander Murray F. Suetter, of the Royal Navy, published in 1908. A more recent work of a somewhat popular nature, but containing much valuable information, is "Submarines, Their Mechanism and Operation," by Frederick A. Talbot.

The Aluminum Air-cooled Cylinder. ANON. (*The Autocar,* vol. xxxix, No. 1137, p. 105, August 4, 1917.)—One great advantage of aluminum, apart from its light weight, is the high heat conductivity of this metal, and, as compared with cast iron and steel, it is of great advantage in an air-cooled engine, where efficient cooling entirely depends upon the rapidity with which heat is conducted by the cylinder metal from its source to the atmosphere. At the temperature at which conductivity comparisons are usually made, copper has nearly twice the value of aluminum, and aluminum five times that of iron. That there are real possibilities for the air-cooled engine is indicated by the successful performance of the Franklin car, which is giving continued satisfaction to its users.

In the recent Frontenac racing car, aluminum enters largely in the engine construction, this metal being used for the cylinder block castings, among other important parts. One way and another, it seems very difficult to avoid the subject of aluminum for engine construction, because, even if we demand water cooling as the only fully satisfactory method for motor-cars, we shall not evade the question of aluminum cylinders with cast-iron liners. The saving in weight between aluminum cylinders with liners and cast-iron cylinders and jackets is so much in favor of aluminum that those who disbelieve in it will have to establish some compromise by adopting a lighter system of jacketing than can ever be achieved in cast iron. In this there will be no novelty, as the sheet-metal water jackets surrounding iron cylinders are very old in motor construction, and at one time almost all the best continental machines had these jackets. In all probability they would not have been abandoned had the earlier methods of getting water-tight joints for these jackets been so successful as those adopted at a later period.

Cracking Hydrocarbon Vapors by Electricity. ANON. (*Electrical World*, vol. 70, No. 7, p. 295, August 18, 1917.)—A process that aims to obtain by means of an electric discharge a greater yield of fixed gases from hydrocarbon vapors is the development of J. G. Davidson and R. W. Ford, of Vancouver, B. C., Canada. Patent No. 1,229,042 has been granted covering the discovery that by passing such vapors through an electric brush discharge field the amount of noncondensible gases is increased. In actual tests it is claimed that by this process the amount of CH_4 in the gas has been increased from about 25 per cent. to approximately 40 per cent., while the amounts of C_nH_{2n} were increased from between 7 per cent. to 10 per cent. to between 20 per cent. and 23 per cent. Ordinarily the gas is conducted through a plurality of conduits formed as vertical pipes, connected at their lower ends to a supply header and at their upper ends to an outlet header, the discharge electrode being formed as wires hung axially in the pipes from an insulated support. The pipes are grounded and the electrodes are connected by a wire to a mechanical rectifier of the usual rotary type included in the high-tension circuit of a step-up transformer, the rectifier connected to ground.

Marking Materials. L. B. BAKER. (*Scientific American*, vol. cxvii, No. 11, p. 195, September 15, 1917.)—If a diamond be drawn across a piece of glass, its path is marked by a scratch, the deepness of which depends upon the amount of pressure exerted in the operation. This scratch, as we all know, is an actual rupture or tearing of the surface of the glass. Again, if a piece of lead be rubbed over a rough surface of steel a mark is made which, contrary to the conditions in the previous example, is composed of the marking material. Finally, if a liquid or semi-liquid composed of dye or coloring matters in suspension, or chemicals capable of reacting to produce color, be placed on a smooth surface and allowed to dry, we have the production of a kind of marking different from that in either of the above examples.

At first sight all three of these methods seem extremely simple in principle; and, indeed, the use of a hard writing object upon a material softer than itself, or the application of dyes and colors, does not offer many perplexing problems for the physicist to explain. But the use of a material which by friction leaves on the writing surface a mark composed of its own substance is not quite so simple. In the first place, disregarding all writing materials which may be made of a sticky composition, it is extremely difficult, if not impossible, to write upon a hard surface, if that surface be smooth or polished. Evidently, then, one of the prerequisites is a writing surface to a greater or less degree rough.

A consideration of equal importance is the nature of the writing substance itself. This must possess the quality of yielding up very minute particles of itself when it is being drawn across the uneven surface of the material written upon. That all soft substances do not possess this property will be evident if an ordinary rubber eraser, appreciably soft to the touch, be drawn over a rough surface of steel. It leaves a mark far less visible than that produced under the same conditions of application by a piece of lead, far harder to the touch than the rubber. Many similar examples might easily be quoted; even in the case of the ordinary pencil, we are familiar with the apparent greater hardness of the graphite core of the pencil as compared with the paper.

A closer examination will disclose the fact that the property really essential to a successful marking material concerns itself with the quantity of coherence existing between the minute particles of the substance, and the relative ease or difficulty with which they detach themselves from each other under the action of abrasion. For instance, the individual particles which go to make up the structure of a diamond are extremely hard themselves, and they are united to each other so strongly that ordinary abrasion on no known substance has the power to tear them apart. On the contrary, the core of a pencil is composed of a material the small individual units of which, although harder to the touch than the paper, are so loosely bound together that the abrasion caused by writing detaches them from their mass.

Under the microscope the surface of ordinary paper is seen to be very rough. The various fibres of which the sheet is made appear on the surface as a tangle of thread-like strands. Because these fibres are more or less rounded in cross-section they are slight depressions or pockets between adjacent fibres. It is these pockets which fill up with the pencil substance and make what we all recognize as the pencil mark. The pencil mark is not a continuous black line, but consists almost entirely of isolated pockets, as described above, each containing a little deposit of graphite. Furthermore, very little mark, if any, is left upon the fibre itself.

The Pyrogenesis of Hydrocarbons. E. L. LOMAX. (*Journal Institution of Petroleum Technologists*, 1916, through *Journal Industrial and Engineering Chemistry*, vol. 9, p. 879, 1917.)—The products of the pyrogenetic treatment of petroleum may be divided into four general classes; namely, permanent gas, illuminating oils, aromatic hydrocarbons, and volatile fuels for internal-combustion engines. These classes also represent, roughly, the lines on which development has taken place. Although the manufacture of permanent gas is of secondary importance in petroleum technology, the earliest work on the pyrogenesis of petroleum was started with that end in view.

The use of illuminating gas made from oil was proposed as early as 1792 by Murdock, and in 1805, as well as in 1821, Henry described the gas obtained by cracking animal oils, fats, and waxes, noticing the formation of ethylene. Between these two dates, John Dalton carried out the first scientific investigation on the pyrogenetic decomposition of hydrocarbons by subjecting ethylene and methane to the action of electric sparks. It is evident that about this time the question of the production of gas from oil occupied the attention of inventors and scientists, for in 1825 we have the classic discovery of benzene by Faraday. The brilliant researches of Berthelot in 1866–1867 on the action of heat upon various hydrocarbons also mark an important epoch in the development of the subject. The results of this work stand to the present day, the whole study being worthy of the great author.

The attention of the oil industry was directed to the question of increased production of illuminating oils by "cracking," an operation that was accidentally discovered in 1861, owing to the carelessness of a stillman who built a strong fire under his still and left it running, intending to return in about an hour. He did not, however, return till about four hours later, when he found the still running a light-colored distillate of lower specific gravity than that which was passing when he left. Experiment showed that a portion of the distillate had condensed upon the upper cooler part of the still and, dropping back upon the hot residue, was decomposed into lower-boiling constituents. This discovery had, however, to some extent been anticipated by Silliman in 1855, who advanced the theory that several of the products of distillation of petroleum were results of heat and chemical change during distillation. The discovery led to a large amount of technical and scientific work on increasing the production from petroleum of illuminating oil, which at that time was the most valuable product obtained.

In the early investigations catalytic action was ignored, but at more recent dates great attention has been given to the value of catalysts, finely divided metals and their compounds being employed. Notable among these is the use of metallic halides, in which field the well-known reaction of Friedel and Crafts has formed the basis for a number of experiments on the decomposition of hydrocarbons. Aluminum chloride has generally been employed.

The demand for volatile hydrocarbons for use as fuel in internal-combustion engines in late years, and the question of obtaining an increased production by the utilization of fractions of crude petroleum of otherwise less value, have stimulated the activities of engineers and chemists in finding a solution to the problem. Prominent among recent developments are the processes of Rittman and Hall. The Rittman process for the manufacture of gasolin and benzene-toluene from petroleum and other hydrocarbons has been extensively exploited in the United States, the investigations which led to this discovery and its large-scale development having been carried on under the direct auspices of the United States Bureau of Mines.

It has long been known that aromatic hydrocarbons can be produced from certain types of petroleum, a process having been patented as early as 1860 for the recovery of oil-gas made from petroleum, but Rittman claims that it has never before been demonstrated that they can be produced in any considerable quantities from any type of oil. In the early part of 1915, however, they were being produced by the Hall process, which if not prior to the Rittman process was at least abreast with it. The benzene-toluene spirit produced by the Rittman process contains considerable quantities of non-aromatic bodies unattacked by strong sulphuric acid, and for the production of trinitrotoluene from the toluene fraction special methods have to be devised. The spirit produced by the Hall process, on the other hand, contains only minute traces of non-aromatic bodies unattacked by strong sulphuric acid, and the toluene produced is as easily nitrated as coal-tar toluene. The cost of the installation appears almost prohibitive. The cost of a plant on the Rittman benzene-toluene process handling about 18,000 gallons of oil per day would be $335,000. With the Hall process a plant capable of handling 10,000 gallons of oil per day would cost about $58,000.

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THE HARAHAN BRIDGE AT MEMPHIS, TENNESSEE.*

BY

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THE great cantilever bridge crossing the Mississippi at Memphis, Tenn., known as the Harahan Bridge, is the second bridge erected at that point and is an important addition to the long list of American cantilever bridges. The bridge was authorized by act of Congress, August 23, 1912, and built by the Arkansas and Memphis Railway Bridge Terminal Company for the joint ownership and use of the Rock Island Lines, the St. Louis, Iron Mountain and Southern Railway, and the St. Louis Southwestern Railway.

The first steel was erected on Pier 1, April 7, 1915. Considerable delay in erection of the river spans was experienced, owing to the almost unprecedented high stage of the river during the summer months, when a low stage may usually be looked for. This prevented commencement of erection when expected. Later, again, when the erection of spans 3 and 4 was barely commenced, the river rose to a stage of 26.6 feet on December 23, 1915, carrying away the falsework between piers 3 and 4, and some five hundred tons of steel beams, stringers and other material, which had been deposited or assembled on the falsework during the initial stage of erection of this span. In order to insure an early

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* Communicated by the Author.

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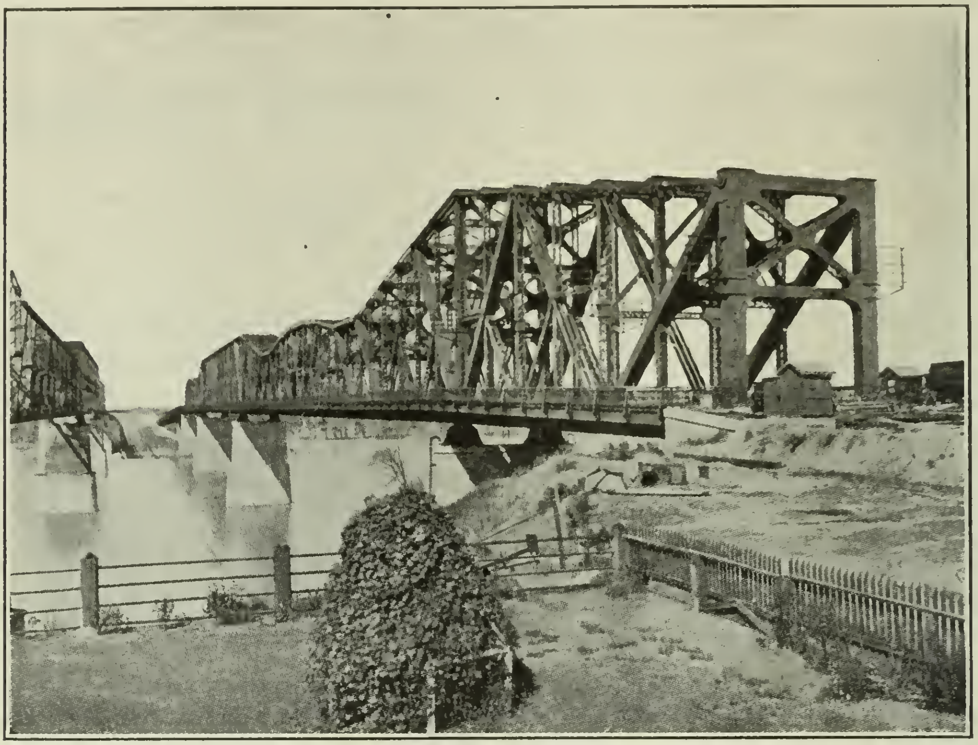
completion of the bridge, a supplemental agreement was entered into between the bridge company and the contractors by which this span would be erected partly without falsework and without waiting for the summer low water. This involved some changes in the plans and the payment of a premium for quick delivery of material. It also became expedient to protect the contractors against loss by high water of such falsework as would still be required for this span. These arrangements permitted the completion of the bridge several months sooner than could have been done had the course of waiting for the low water been carried out. The last pin was driven in this span on June 28, 1916. The first train was run over the bridge on July 14, 1916, and the bridge opened to railway traffic on the day following.



The Harahan Bridge at Memphis.

GENERAL DESCRIPTION.

The bridge crosses the Mississippi River two hundred feet upstream from, and parallel to, the old bridge now owned by the St. Louis and San Francisco Railroad, and which in this report will be called the Frisco Bridge. The eastern end of both bridges is within the city limits of Memphis, Tenn., while the western end lands in Crittenden County of the State of Arkansas. At ordinary low water the Mississippi River at this point is about 1900 feet wide between banks, while at bank-full stage it is about 2050 feet wide. At extreme high-water stages the river overflows the low land in Arkansas for several miles inland on the bridge line. This made it necessary to construct a long, open viaduct approach and thus provide a large cross-section to take care of flood waters, as required by the War Department. The Tennessee shore is formed by bluffs on which the city is built. The top of these bluffs is nearly at the same elevation as the bridge deck, so that no long approaches were required at the east end of the bridge. The structure covered by this report consists of two main portions—the main bridge and the Arkansas viaduct. The main bridge comprises from east to west one anchor arm 186 feet 3¾ inches long, one channel span 790 feet 5¼ inches long, one fixed or centre span, 621 feet long, one shore span 604 feet 1½ inches long, and one deck span 345 feet long. These rest on six piers, the easterly one being an anchor pier acting both as an anchorage and as an abutment. The total length of the main bridge, counting between centres of extreme end pins of the spans, is 2548 feet 10½ inches, including a distance of 2 feet between centres of end pins at pier 4. Owing to the proximity to the Frisco Bridge, the river piers were necessarily located exactly opposite those in the Frisco Bridge, but, for reasons explained further in this report, pier 4, which is placed on the west bank of the river, was moved 17 feet towards the river, thus making the shore span shorter than the corresponding span in the Frisco Bridge. Permission to do so was received from the War Department. The main bridge is built to provide a vertical clearance of 75 feet above high water of 1887. This high water corresponds to elevation 215.85 of the U. S. Government gauge or to 33,14 of the Weather Bureau datum. The viaduct is composed of plate girder spans placed on steel towers, which in turn rest on concrete piers. There are twenty 80-foot and nineteen 40-foot spans, making the total length of the viaduct 2360 feet. The total length of the bridge between centres of extreme end bearings is 4912 feet 9½ inches. The superstructure of the main bridge was designed as a four-span cantilever system continuous over five piers, the deck span being independent. This is a very similar disposition to the one followed in the Frisco Bridge, the difference being: first, that the anchor arm has been made shorter to obviate any reversal of stress in the anchor bars, which will thus always be in tension; and, second, in the length of the suspended spans, which are shorter than in the Frisco Bridge. These two modifications resulted not only in greater economy of material, but also in reducing the difficulties of cantilever erection by reducing the stresses on adjusting devices at the juncture of the suspended spans and the cantilever arms. The shifting of pier four 17 feet toward the river permitted to shorten the suspended spans by 34 feet, and still have the three cantilever arms and the two suspended spans respectively alike. Both the main bridge and the viaduct are double-track structures, two wagon roadways being also provided on brackets outside of the railway deck. The distance centre to centre of tracks is 14 feet. A horizontal clearance of 30 feet and a vertical clearance of 24 feet above base of rail have been provided. The clear width of each wagon roadway is 14 feet.

Starting at the Memphis end on the railway deck, there is an ascending grade on the anchor or easterly span of 1.1 per cent.; the grade then becomes level and remains so over the three main river spans, and becomes 0.6 descending over the deck span and 1.126 per cent. descending over the entire viaduct. The wagon roadways follow the same grades until pier 4 is reached, and then descend with a 3 per cent. grade for a distance of 2030 feet 11 inches, and then continue level until they reach the county road.

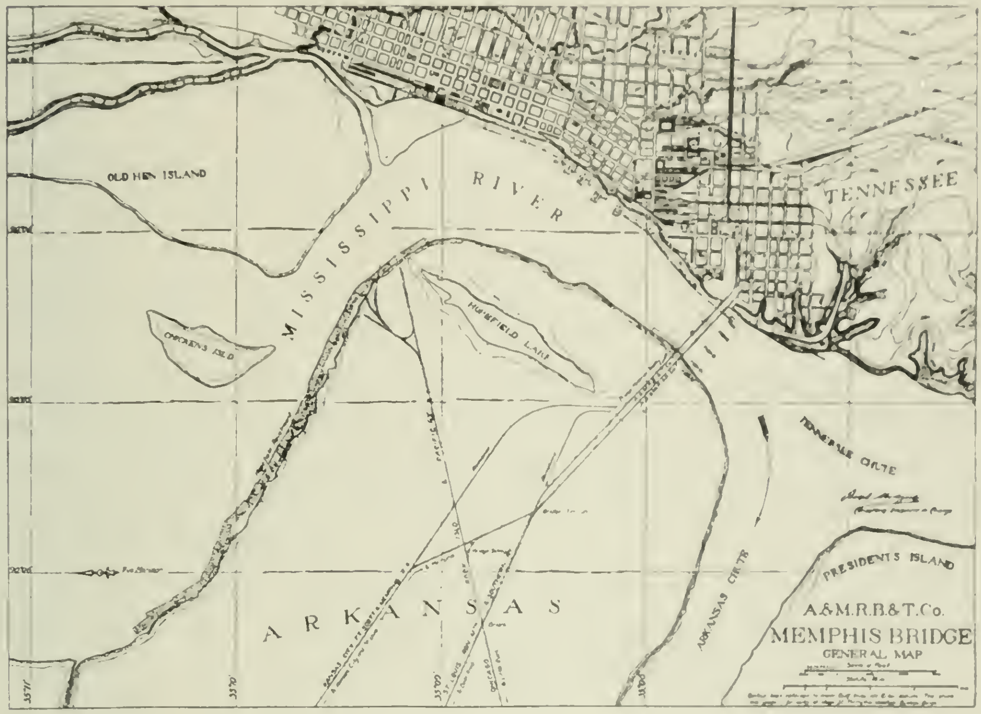
MAIN SUBSTRUCTURE.

Description.

The substructure of the main bridge consists of five piers, numbered consecutively from 1 to 5, pier 1 being placed on the east shore, and one combined anchor pier and abutment. The foundations for piers 1 to 5 were built by sinking caissons by pneumatic process. The foundation for the anchor pier was built in open excavation.

Borings taken before work was commenced revealed very much the same character of materials as were found in the Frisco

Bridge; namely, fine to coarse sand, thin strata of gravel and clay, and a heavy stratum of hard blue clay, which carries the foundations of the Frisco Bridge. No bed rock was found, although the borings extended 200 feet below low-water level. It was therefore decided to sink the foundations to the same stratum of hard blue clay. Experience in the Frisco Bridge with this hard clay taken out of the caissons showed that cubes with two-inch sides, unsupported laterally, could, with one exception, withstand a pressure of at least 100 pounds per square inch, or 7.2 tons per square foot. It is fair to assume that in case of material supported on all sides the resistance would be greater. Crude experiments made in the caisson working chambers of this bridge by Resident Engineer Case seem to justify that assumption. It was therefore decided that a net pressure of 5 tons per square foot on the clay would be a safe load to impose, and the dimensions of the caissons were determined accordingly. The following table shows the various pressures on the foundations of piers 1 to 5, including full live load:



Site of the Memphis Bridge, Memphis, Tennessee.

PRESSURES ON FOUNDATIONS.

Weights in Tons of 2000 Pounds.

	Pier 1		Pier 2		Pier 3		Pier 4		Pier 5	
Timber, iron, and concrete in foundations	10110		9330		9470		7800		5190	
Concrete in working chamber and shafts	1180		1390		1500		1620		390	
Granite masonry concrete backing, except pier 5, which is all concrete	7780		13730		14030		6770		1170	
Total weight of pier	19070		24450		25000		16190		6750	
Superimposed earth	1810		0		2830		1180		80	
Superimposed water to zero gauge	0		2740		1310		0		0	
Superstructure dead load	5670		5600		5600		1140		850	
Superstructure live load	3870		3900		3900		1910		1070	
Total downward pressure		30420		36690		38640		20420		8750
Deduct for water reaction at zero gauge	5310		10920		11250		4950		2090	
Deduct for earth displaced	8110		4000		6950		5450		3450	
Deduct for skin friction at 400 pounds per square foot	2850	16270	2320	17240	2710	20910	2660	13060	2300	7840
Net weight on foundation		14150		19450		17730		7360		910
Pressure on foundation in tons per square foot	4.4		5.1		4.7		3.1		0.8	
Horizontal dimensions of caissons	40'x80'		42'x90'		42'x90'		31'x77'		25'x46'	

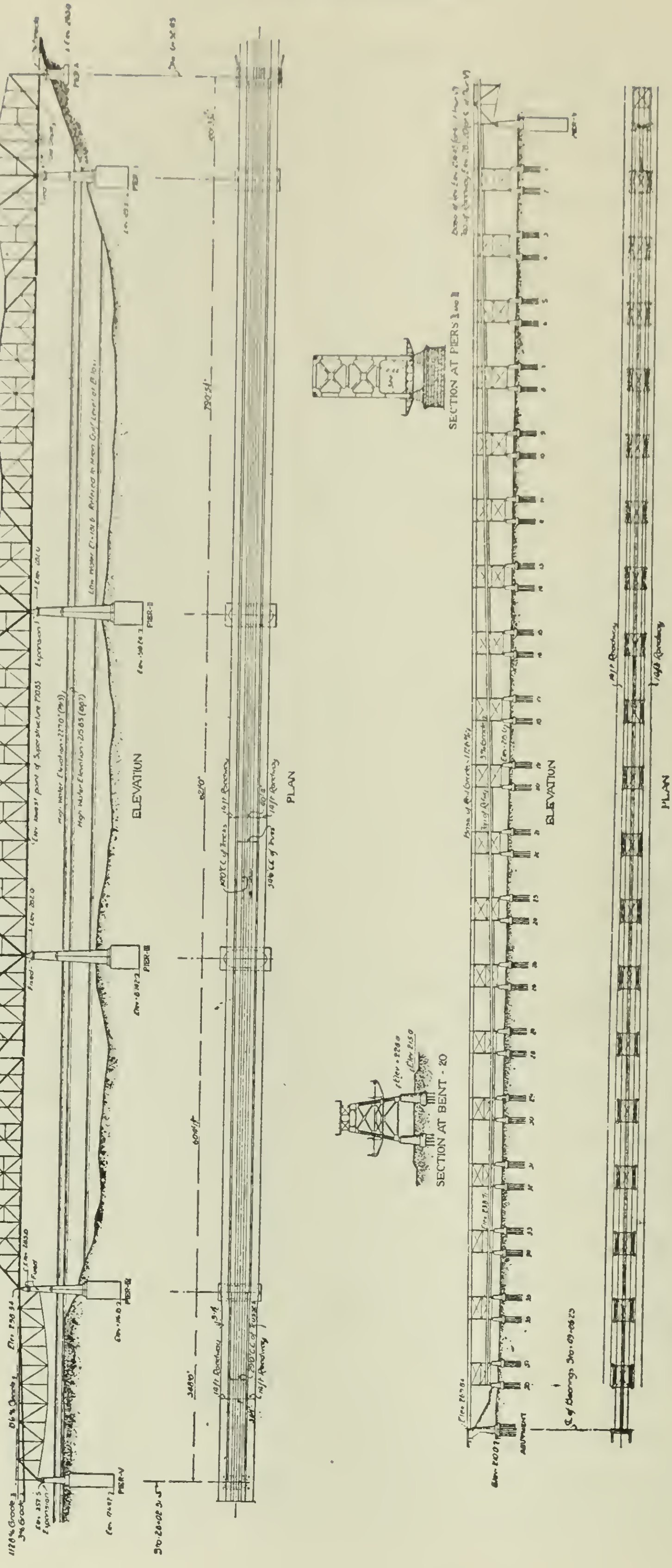
The deduction of 400 pounds per square foot for skin friction is conservative. As a matter of fact, while making the last drop in pier 4 conditions were such that a practically exact measurement of the skin friction could be taken, and this was found to be 800 pounds per square foot. It is probable that this friction will not be less than 1000 pounds per square foot after the materials are well settled around the piers. The above table also gives the horizontal dimensions of each caisson. The caissons were built of timber with steel cutting edges. They were filled with concrete made of Portland cement mortar and gravel. A small quantity of crushed rock was used in pier 2 when gravel could not be obtained in time. In piers 1, 2, and 3 steel rods were imbedded in the concrete just above the roof of the caisson working chamber to secure additional strength during the first stages of sinking. The general method of sinking was that usually followed in similar cases. The wet " blow out " was used for excavating sand or silty clay, and buckets through air-lock for clay. Elevators were provided in piers 2 and 3 for the use of men in going in and out. The method of sealing the working chamber differed from that used in the Frisco Bridge, and which was generally used at the time that bridge was constructed:

instead of using dry concrete for the entire volume of the chamber, which required men for ramming it in benches, and consumed considerable time, dry concrete was used only to support the edges of the caisson and the crossbeams, under which it was rammed in, and then wet concrete was poured in until the chamber was filled. By that method the time required for sealing a chamber was generally under 48 hours, meaning that the rate of placing concrete in the chamber was about 15 cubic yards an hour. The piers above the caissons, except pier 5, are of granite backed with concrete, except the belting courses and two courses below, which are backed with granite stones of same thickness as the face stones. The coping of these piers is entirely of granite. The bearing surfaces under the steel pedestals have been carefully dressed after the stones were set. The thickest course in the piers is 36 inches. The face stones have a rock or quarry face with projections not exceeding three inches, except the copings, beltings, and starlings. The copings are laid with close joints and are bush-hammered throughout. A four-inch draft line is cut around the lower edge of the belting course and on each side of each nose line. The curved faces of the upstream cutwater and the surfaces over the pointed ends of each pier are fine pointed, with no projections greater than one-half inch; the projecting portion of the lower bed of the coping and belting courses are bush-hammered.

Reinforcing rods 1¼ inches square were used in the concrete backing of the first seven courses, and every seventh course above that, and in the four top concrete-backed courses.

Pier 5 was built entirely of concrete reinforced by steel rods.

PIER 1.—The caisson for this pier was built on shore in place. It was supported on the sand and gravel of the bank. Work was begun on setting the cutting edge on November 23, 1913. The cutting edge was placed 6 inches nearer shore than the desired final position, to provide for the crowding effect of the bank. The caisson was lowered 20 feet, of which 5 feet were below the level of the water, before the air-pressure was applied. Its final position was correct, showing that the 6-inch allowance for crowding was right. The upper eight feet of the crib were of light construction and built of 3-inch vertical planking to act as a form for the concrete. Compressed air and water for sinking were supplied from the floating compressor plant moored near by.

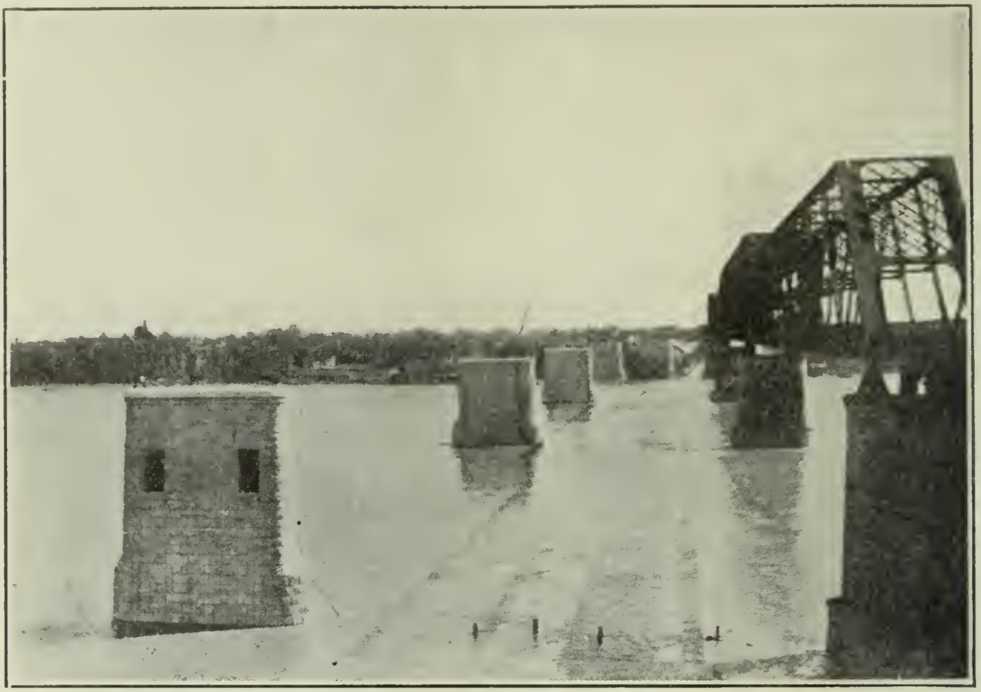


Arkansas and Memphis Railway Bridge and Terminal Company. The Memphis Bridge—General elevation and plan.

PIER 2.—This pier is located in the deepest portion of the river, and because of the great depth of water at this place precautions had to be taken which were considered unnecessary for the other piers. To protect the river bottom from scouring before the landing of the caisson, and also after the work is done, a willow mat 200 feet wide and 300 feet long was sunk at the site of this pier, the long dimension being parallel with the stream and the mat placed so that it extends 200 feet upstream and 100 feet downstream from the centre line of the bridge. The caisson for this pier, as well as for pier 3, was built on a floating pontoon and launched by flooding the pontoon and separating it on its long centre line. In building the caisson special care was taken with the caulking. The diagonal planking in the caisson chamber roof was laid in pitch, which was also used over all the seams in the roof. This was done to reduce the leaks, so that they could easily be handled by pumps. To assist in carrying the excess weight of the caisson during the initial stages of penetration, 24 12-inch by 12-inch vertical timbers and a horizontal belt of 12-inch by 12-inch timbers were bolted to the caisson walls on the outside and just above the caisson chamber. These timbers increased the sinking friction of the caisson sufficiently to enable the excess weight to be easily handled. Before the caisson was placed in position a quantity of sacks filled with sand were deposited on top of the mat so as to reduce the depth of water for the purpose of easier landing of the caisson. About 6 feet in height was thus gained, reducing the depth of water from 51 feet to 45 feet at the time of landing. The greatest head of water during compressed-air work occurred in this pier. It reached 107 feet during the sealing of the working chamber, while the air-pressure was 48 pounds per square inch.

PIER 3.—A small amount of sand sacks were used to level up the river bottom before the caisson was landed. The depth of water at the time of landing was 30 feet. The mat and riprap placed during the construction of the Frisco pier were found over the downstream half of the caisson.

PIER 4.—The caisson for this pier was built in place. The cutting edge was located 18 inches toward shore to compensate for the crowding effect of the bank. The river side of the caisson was supported during construction by a series of boxes filled with sand and sunk about 8 feet into the silt before the cutting edge was assembled. The caisson was carefully lowered and all necessary precautions taken for keeping it level. In spite of that, the plane of the cutting edge developed a warp of 2 inches before sufficient friction on the sides was attained and sufficient air-pressure applied to assist in lowering the caisson. The air plant for this caisson, as well as for caisson 5, was located 400 feet inshore on an old dike above ordinary high water. The allowance of 18 inches for the crowding effect of the bank proved to be too great, and it was with considerable difficulty that the caisson was finally brought to within 3 inches of its true position. After the cutting edge reached a depth of 65.5 feet below low water, or elevation 116.1, the excavation was carried down 3 feet below the cutting edge to a stratum of rock a few inches in thickness overlying the hard blue clay.



General view of completed piers, looking east.

PIER 5.—The caisson was built in place. The material traversed was almost entirely sand, very little being removed through the bucket locks. On the morning of April 9 a deplorable accident occurred in which 9 men lost their lives. The men of the gang going in to relieve the crew in the working chamber were overcome by gas as they were about to lock in, and apparently instantly killed. No definite evidence as to the nature or origin of the gas which had accumulated at the bottom of the main shaft above the lock has been obtained, but the probability is that the accident was due to carbon monoxide formed by the ignition and combustion of methane (CH_4). The men in the working chamber felt no ill effects whatever, and were taken out one by one through the material locks.

ANCHORAGE PIER.—The anchorage pier was built in open excavation 48 feet deep, and, although the clay through which this excavation was made stands well on a vertical face when dry, it was deemed necessary, in view of the considerable depth, to use heavy timbering. The pier was built of concrete faced with granite above the ground line and reinforced by steel rods. The anchor girders were entirely imbedded in the concrete. Wells were left around the anchor bars and filled in later, after the bars had been stretched by subjecting them to a stress, as explained in the chapter on superstructure.

QUANTITIES AND COMPARATIVE UNIT COSTS OF PIERS.

The substructure of the Frisco Bridge was built with the railway company's forces; that of the new bridge was built under contract based on cost and percentage. In both cases, therefore, an accurate account of cost was possible. The design and character of the piers in both bridges are very similar. In both, the piers have been sunk by pneumatic process to about the same elevations, through very similar materials; in both, the face stones are of granite, except that in the Frisco Bridge some limestone facing was used below low water. Because of this similarity it was deemed of interest to prepare unit costs of the various portions of the piers and compare the results with the Frisco Bridge, as given in Morison's report.

VOLUME OF PIERS IN CUBIC FEET.

	Pier 1	Pier 2	Pier 3	Pier 4	Pier 5
Foundation	189,440	192,780	193,725	147,278	93,150
Sinking (actual volume sunk)	243,616	195,642	281,666	182,772	98,088
Masonry	101,986	173,632	180,074	86,282	19,062

UNIT COST IN DOLLARS PER CUBIC FOOT.

	Pier 1	Pier 2	Pier 3	Pier 4	Pier 5
				All concrete	
Sinking (to actual volume sunk)..........	0.141	0.310	0.206	0.139	0.109
Foundation (excluding sinking)	0.469	0.759	0.631	0.509	0.494
Foundation (including sinking) (to total volume foundation)	0.649	1.074	0.931	0.682	0.508
Masonry (to total volume shaft)...........	0.785	0.721	0.757	0.889	0.371
Foundation, sinking, and masonry (to total volume of pier).....................	0.697	0.906	0.847	0.758	0.568

Morison's report on the old Memphis Bridge gives unit costs, which are on a comparative basis, with the following exceptions: Morison's figures do not include concrete below cutting edge or clay left in chamber above cutting edge, and there are included credits from sale of plant which are not included in the figures for the new bridge. Morison's report also includes the volume of the voids, or wells in the body of the piers. The unit costs which compare with the last line of the former table are as follows:

UNIT COST IN DOLLARS PER CUBIC FOOT OF PIERS OF THE FRISCO BRIDGE.

	Pier 1	Pier 2	Pier 3	Pier 4
Foundation, sinking, and masonry (to total volume of pier)	0.787	0.832	0.999	0.801

MAIN SUPERSTRUCTURE.

Description.

The main superstructure consists of a continuous cantilever system of four spans and one deck span, the lengths of which have been given elsewhere. It carries a double track for railway and two roadways, one on each side, supported on brackets outside of the trusses.

The principal reason for adopting the cantilever system for the river spans was that it enabled the channel span between piers 1 and 2, which is placed over the deepest portion of the river, to be erected without falsework. It would have been extremely hazardous, if not impossible, to erect the 790-foot channel span on falsework. It has been suggested that a fixed or simple span of that length could be erected by cantilever method, but a fixed span of that length has not yet been built, and if built by cantilever method would require a large addition of metal near the ends in the top and bottom cords, to take care of erection stresses. But, even without that addition, a system of fixed spans would weigh considerably more than the one used. It was originally planned to use falsework in all spans except the channel span, but, owing to high water, as already described, the cantilever arm projecting from pier 3 and the east half of the semi-suspended span between piers 3 and 4 were erected by cantilever method, and only the west half of the latter on falsework.

The superstructure is built partly of carbon steel and partly of a nickel-chrome alloy, known under the name of "Mayari" steel, which is manufactured from Cuban ores containing both nickel and chrome very nearly in right proportions to produce proper bridge material of excellent quality. Nickel steel had been used a short time previous to the construction of this bridge in at least two large bridges where strength of the metal became a source of economy. That alloy was artificially produced by the addition of from three to three and one-half per cent. of nickel and is consequently expensive. Other alloys have also been suggested from time to time for bridgework. In order to receive the benefit of competition and at the same time make a decision possible as to the metal to be used to the best advantage in the structure, the following procedure was adopted: Two distinct designs were worked out in detail, one for carbon steel with only the eye-bars of alloy steel, and one of alloy steel trusses and bottom lateral system and carbon steel floor system, using in both designs unit stresses fifty per cent. higher for alloy tension members and forty per cent. higher for alloy compression members than for carbon steel. The specifications were then prepared in such a way as not to exclude any alloy of nickel and other metals which the manufacturers might desire to submit for use, provided it met the physical requirements, and provided their composition did not contain an excess of injurious elements. Tenders were received on both the carbon and the alloy designs, and the alloy design, costing approximately $68,000 less than the carbon design, was adopted.

Expansion for the trusses was provided on pier 2 by means of specially designed segmental roller bearings. Expansion is also taken care of at the junction of each cantilever arm with the corresponding suspended span and at the shore end of the anchor arm. Anchorage is provided by means of eye-bars attached to steel girders which are placed near the bottom of the anchorage pier. Both the girders and the anchor bars are imbedded in concrete, but wells were left open around the anchor bars until these bars were stretched to correspond to the greatest stress which they will be expected to carry under a moving live load. This was accomplished by a special device, consisting of bearing blocks and wedges placed on the anchor pier coping. By means of these wedges a requisite tension stress was introduced into the bars, and while they were thus stretched the wells were filled with concrete packed tightly around the bars. In this manner there will be no variation of length in the imbedded anchor bars due to varying loads. The expansion is taken care of by the oscillation of the vertical bars leading from the anchorage to the top chord.

The superstructure was designed to carry a loading of Cooper's E 55 on both tracks, and in addition thereto 600 pounds per foot of roadway on suspended spans, and 500 pounds on the remainder of the bridge. Members subject to concentrated panel loading were calculated for E 55 locomotives on both tracks with 1120 pounds per lineal foot of the nearest roadway. The stresses in the entire bridge have also been calculated on the assumption of a loading of Cooper's E 75 on each track and 1000 pounds per foot of truss for roadways. Under this "test load," the stresses will not exceed six-tenths of the elastic limit of material in any member, which means that such a loading could be operated over the bridge with perfect safety at moderate speeds.

Arkansas approach viaduct, October 1, 1915.

The weights of metal in the completed superstructure are given in the following table:

	Alloy steel		Carbon Steel		Total	
Anchor arm—						
Chords and end posts	927,370		115,620		1,042,990	
Web system	261,862		842,206		1,104,068	
Railway floor system			364,088		364,088	
Wind and sway bracing			272,473		272,473	
End bearings on pier			312,001		312,001	
Roadway floor system			160,428		160,428	
Railing			43,500		43,500	
		1,189,232		2,110,316		3,299,548
Anchorage material		58,028		181,594		239,622
Three cantilever arms—						
Chords and end posts	3,749,668		37,500		3,787,168	
Web system	644,372		496,494		1,140,866	
Railway floor system			905,712		905,712	
Wind and sway bracing	162,420		402,383		564,803	
Roadway floor system			402,868		402,868	
Railing			130,800		130,800	
		4,556,460		2,375,757		6,932,217
Suspended and semi-suspended spans—						
Chords and end posts	3,678,332		48,240		3,726,572	
Web system	1,307,833		589,678		1,897,511	
Railway floor system			1,515,848		1,515,848	
Wind and sway bracing	86,390		396,040		482,430	
End bearings on pier 4			58,699		58,699	
Roadway floor system			635,840		635,840	
Expansion devices			57,005		57,005	
Railing			195,800		195,800	
		5,072,555		3,497,150		8,569,705
One fixed span—						
Chords and end posts	4,640,577		53,900		4,694,477	
Web system	2,105,649		762,871		2,868,520	
Railway floor system			1,161,260		1,161,260	
Wind and sway bracing	80,650		539,480		620,130	
End bearings, piers 2 and 3			681,195		681,195	
Roadway floor system			459,601		459,601	
Railing			145,769		145,769	
		6,826,876		3,804,076		10,630,952
One deck span—						
Chords and end posts	327,522		716,873		1,044,395	
Web system			539,700		539,700	
Railway floor system			600,654		600,654	
Wind and sway bracing			200,121		200,121	
End bearings piers 4 and 5			82,110		82,110	
Roadway floor system			301,031		301,031	
Railing			81,000		81,000	
		327,522		2,521,489		2,849,011
Railway guard angles, floor bolts, wire supports, and pier ladders			331,809		331,809	
Total—Main Bridge		18,030,673		14,822,191		32,852,864
Adjusting devices		61,174		351,390		412,564
Grand total—Main bridge		18,091,847		15,173,580		33,265,428

The railway and roadway decks are built of creosoted timber. In view of the considerable depth of water between piers 2 and 3 and the necessity of erecting the fixed span on falsework, it was decided to protect the river bottom by sinking woven willow mats over the entire space between the piers and on a width of 200 feet. Special weaving barges were leased for that purpose, and the mats were woven and sunk in place by means of riprap. It is believed that without this precaution the unusual high water in December, 1915, would have endangered this span very seriously. As it was, great pressure was being exerted against the falsework by the accumulated drift, which caused the span to deflect downstream approximately eight inches. Owing to the fact that the lateral system was completely bolted, no damage was done.

It was intended to proceed with the erection of the cantilever arm and semi-suspended span between piers 3 and 4 as soon as the fixed span was erected. To that end, falsework had been placed between these piers and some steel work assembled on top of the falsework and a gantry traveller built to handle the steel. On December 23, as already described, the falsework between piers 3 and 4 went out, due to high water. It was then decided to complete the channel span between piers 1 and 2 while arrangements were being made for replacing the steel lost with the falsework and modifying the details of the span, so as to adapt it to cantilever erection.

The first train, carrying the officials of the bridge company, ran over the bridge on July 14, 1916, and the bridge was opened for traffic the following day.

ARKANSAS APPROACH VIADUCT.

This viaduct is 2363 feet 11 inches long between centre of end bearings, and consists of an alternating series of 40- and 80-foot plate girders, 40-foot spans forming towers. The piers for the towers are of concrete and built on concrete piles. The steel was manufactured under the writer's standard specifications for bridges of 1911. No other steel was to be used in the viaduct, and, as the work is of a simple nature, these specifications were deemed sufficient. The weights of steel are given in the following table:

	Carbon steel, pounds
Railway floor	4,824,900
Roadway floor	2,752,440
Towers	4,131,810
Railing, guard angles, and refuge platforms	445,910
Total	12,155,060

The total quantities of the principal materials in the main bridge and approaches are as follows: Timber in foundation, 3270 M.B.M.; concrete in piers and foundations, 43,000 cubic yards; granite masonry in piers, 9467 cubic yards; steel in superstructure, 45,420,488 pounds; creosoted timber in railway and roadway decks, 2090 M.B.M.

The Liberty Motor. ANON. (*Aerial Age*, vol. vi, No. 2, p. 53, September 24, 1917.)—One of the first problems which confronted the War Department and the Aircraft Production Board after the declaration of hostilities was to produce quickly a dependable aviation motor. Two courses were open. One was to encourage manufacturers to develop their own types; the other to bring the best of all types together and develop them. The necessity for speed and quantity production resulted in the choice of the latter course. By the inspiring coöperation of consulting engineers and motor manufacturers, who gave up trade secrets under the emergency of war needs, a new motor, designated by the Signal Service as the "liberty motor," has been developed for the use of the United States air service, and is the country's main reliance for the rapid production of this important component of high-powered battle planes.

In power, speed, service ability, and minimum weight the new engine invites comparison with the best the European war has produced. One of the chief rules adopted at the beginning of the designing work was that no engineer should be permitted to introduce construction which had not been tried out: there was no time for theorizing. The new engine is successful because it embodies the best thought of engineering experience to date. Not only did consulting engineers of this country furnish ideas, but representatives in the United States of England, France, and Italy contributed to the development of this motor.

While it is not deemed expedient to set forth in detail the satisfactory performances and the mechanics of the new motor, it may be said that standardization is a chief factor in the development of the

Government's motor. Cylinders, pistons, and every other part have been standardized. They may be produced rapidly and economically by a great many factories operating under Government contracts, and may be rapidly assembled, either by these plants or at a central assembly plant. It should be understood that the "new" motor is not, strictly speaking, an invention. No doubt it has what are in effect new values, but the real result achieved is the combination of the strong points of all the available contrivances of the kind.

Failure of the Carburizing Process. E. F. LAKE. (*Proceedings of the Steel-Treating Research Club of Detroit* (through *Machinery*) (London), vol. x, No. 258, p. 620, September 6, 1917.)—The carburizing or cementation process of adding carbon to iron or ferrous alloys is so ancient that its origin cannot be traced. Metal workers for many centuries made good steel by this process, but they did not know that it was the carbon they added to the metal that gave the desired results. Although any of the new alloy steels, properly worked and heat-treated, will give better results than carburized steel, the latter is still much used in the manufacture of some important machine parts, especially in the automobile industry. Low-carbon steel can be machined more readily than high-carbon steel, and this is one of the reasons why the carburizing process has remained, but the principal argument advanced in favor of carburized parts is that they have a hard outer surface that will resist wear to the greatest degree and a tough centre that will prevent breakage. The value of these properties, however, is less than might be expected.

The steels containing from 0.12 to 0.18 per cent. carbon, which are generally used for carburized parts that contain approximately 1 per cent. carbon in the outer shell, seldom have an elastic limit of more than 40,000 pounds per square inch, and this cannot be increased much more than 5000 pounds by any heat-treatment. If steel with a high enough carbon content to give the best wearing surface is used, the elastic limit can be raised to more than 100,000 pounds per square inch. In the early days of the bicycle, ball and roller bearings first came into general use. Then the cups, cones, races, and even the balls and rollers, were carburized. Manufacturers soon learned, however, that the hard outer shells of the balls would compress against the soft centres and cause them to deform; then the bearings soon failed. Many of the balls would also break and crack between the hard outer shell and the soft core, causing the shell to peel off. When the manufacturers resorted to a high-carbon steel and gave the balls a uniform hardness clear to the centre, they found that a given size ball would carry a much larger load. Later chromium steel was found best for this purpose. At present high-grade ball bearings outwear automobiles, carrying more than twice the load they bore in the bicycle days.

STUDIES IN ACTINOCHEMISTRY.*

BY

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INTRODUCTION.

Modern scientific experiments and theories have established that all organic compounds are the result of chemical change and that light is essential to most forms of organic life. That the chemist is interested in the chemical actions affected by light and radiations of similar character follows as a matter of course.

The action of chlorophyll in plants upon carbon dioxide and water brought about by sunlight or artificial light produces the most marvellous chemical changes, such as formation of sugars, glucosides, starches, essential oils, cellulose, camphor, rubber, alkaloids, gums, resins, etc.

Photography, with all its beauty and manifold applications, would not be possible were it not for the chemical action of light. The physicist, with his well-constructed camera, is able to form a beautiful image, but making that image permanent is a chemical process. Again, the chemist has been called upon to furnish dyes to be used in paints, wall-paper, inks, clothing, etc., that will not fade when exposed to light. The bleaching of cloth by the old process of allowing it to lie on the grass in the sunlight is due to a chemical reaction. The tanning of the skin by sunlight is evidence of a chemical reaction produced by light. Because of the magnitude of the field it has come to be recognized as a distinct branch of chemistry, to which the name "Photochemistry" or "Actinochemistry" has been applied; the latter being preferable because of its more inclusive meaning.

Eder[1] pointed out that the chemical action of light was closely connected with optical absorption: those rays which act chemically on a substance must be absorbed by it. He points out further that, while waves of certain lengths appear to produce specific effects, light of all colors, from extreme violet to extreme red, can cause chemical action. The following table (Fig. 1), copied from Bigelow,[2] gives a graphic description of the range of the rays of radiant energy, any of which may be capable of increasing the activity of chemical change. Attention is called particularly to the extremely small proportion of this energy which is capable of affecting our sense of sight, and to the still smaller percentage which is available for use when the ordinary apparatus and conditions employed by chemists are used. This is further indicated by the following table copied from Curtis:[3]

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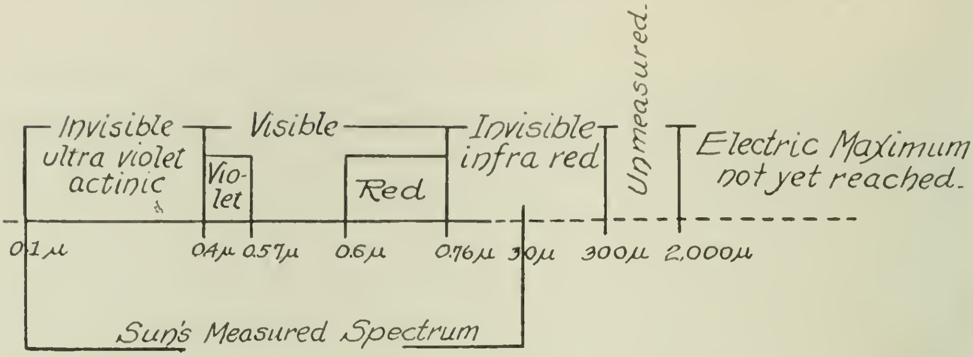
* Communicated by the Author.

[1] "Handbuch der Photographie," 2d ed., 7, 180 (1892); Fr. Bancroft, *Jour. Phys. Chem.*, 12, 209–278 (1908).

FIG. 1.



THE LOWER LIMITS OF TRANSPARENCY.

Flint glass	One centimetre thickness transmits from 50 to 80 per cent. at 350 μμ. Less than 1 per cent. is transmitted at 305 μμ.
Uviol glass	Lower limit at 253 μμ.
Fluorite	One centimetre thickness transmits 83 per cent. at 186, and the transparency is still high at 100 μμ.
Rock salt	Transparency is high at 186 μμ.
Quartz	Transmits 94.2 per cent. at 222 μμ and 67.2 per cent. at 186 μμ; at beyond 186 μμ the transparency falls off rapidly.
Calcite	Less transparent than quartz for short waves.
Mica	Strongly absorbs the short waves.
Water	Transparency is high at 193 μμ. At 186 μμ it is less transparent than is quartz.
Glycerine	Transparency is high at 240 μμ.
Canada balsam	Transparency is high at 330 μμ.
Gelatine	Transparent down to 257 μμ.
Air	Transparency is high at 194 μμ; at 186 μμ the absorption is very high, and no waves shorter than 165 μμ are transmitted.

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[2] "Theoretical and Physical Chemistry," p. 100 (1914).

[3] *Metallurgical and Chemical Engineering,* 14, 184 (1916).

In the thesis which follows, the similarity between the effects produced by the different forms of radiant energy, namely, radiant heat, light, and electricity, will be pointed out. As subjects for study the following have been selected: "The Effect of Chemically Acting Rays on Chlorine," "The Effect of Chemically Acting Rays on Nitrogen," "The Effect of Chemically Acting Rays on Nicotine," and "The Effect of Chemically Acting Rays on the Hydrogenation of Oleic Acid."

THE EFFECT OF CHEMICALLY ACTING RAYS ON CHLORINE.

In his dissertation on the conservation of energy, Helmholtz [4] classified the chemical actions of light as those "by which the light only gave the impulse to the activity of the chemical change analogous to substances which act catalytically," the rate of reaction being accelerated or retarded by light; and, second, "those where the chemical change is opposed," the radiant energy being converted into chemical energy. The reactions here are reversible, and it is a well-known fact that the rate of reaction in the formation of certain chlorine compounds is accelerated by the action of light.

As examples of this phenomenon may be cited, *first;* the combination of chlorine and hydrogen. That light was a factor of prime importance in bringing about this reaction was demonstrated according to Burgess and Chapman [5] and Mellor [6] by William Cruickshank in 1801.[7]

The work of Gay Lussac and Thenard,[8] Seebach,[9] and Dalton,[10] who studied particularly the explosive combination of these gases under the influence of light, confirmed the phenomena. The question was next discussed by Draper,[11] whose researches were quantitative. He was able to establish the fact that the so-called absorption law,[12] which afterwards bore his name, probably because of his having given it prominence in chemical literature, though previously announced by Grothuss[13] and now modified by Bancroft, applies in this phenomenon. He stated that the property of chlorine to combine with hydrogen after exposure to light was permanent, the rays so absorbed becoming latent and the effect lasting an unknown time.

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[4] "Ueber die Erhaltung der Kraft," 1847, p. 25 (see Ostwald's Klassiker, No. 1).

[5] *J. Chem. Soc. Trans.*, 89, 1399–1439 (1906).

[6] *Ibid.*, 79, 216–238 (1901).

[7] *Nicholson's Journal,* 5 (i), 202 (1801).

[8] *Mem. Phys. Chim. Soc. d'Arcueil,* 2, 340 (1809); *Gilbert's Ann.*, 35, 8 (1810).

[9] Seebach, 1910; Goethe, Farbenlehre fr. Weigert (*Samm. Chem. und Chem. Tech. Vortrage,* 17, 183 (1911).

[10] "A New System of Chemical Philosophy," 2, 189 (1811).

[11] *Phil. Mag.*, 23, 401 (1843); 25 (3), 9 (1844); 26 (3), 473 (1845); 27, 327 (1845); "Draper's Collected Memoirs," 1878.

Bodenstein and Taylor[14] have recently conducted experiments to ascertain how long the activity produced by illuminating chlorine persists, and found that it lost its activity in 1/1600 second.

They are of the opinion that statements in the literature relative to the existence of active chlorine for considerable periods are based on experiments carried out with impure gases, the action observed in these cases being due in reality to some entirely different cause.

Very extensive work on the combination of hydrogen and chlorine in the presence of light was carried on by Bunsen and Roscoe.[15] These investigators studied the application of the optical laws for the chemically acting rays and found that the distance law and the reflection laws and Beer's absorption law[16] were valid for the reaction taking place between chlorine and hydrogen in the presence of light. Webster[17] found that certain of the wide bands in the visible spectrum of chlorine do not obey the Beer's law. It has been pointed out that these results are not in accord with the theory of Helmholtz, which assumes a viscous resistance to the motion of a vibrating electron.

Cruickshank[18] has noticed that the reaction was not immediate. Bunsen and Roscoe showed that its velocity increased with time to a maximum, which then remained constant till the reaction was complete. They termed this time of delayed action "the period of induction." This so-called "period of induction" has been the subject of much discussion, though the theory relative to it which is accepted most generally at present is that of Van't Hoff, who considers that the period of induction is not a real and genuine characteristic of a simple chemical change, but that its existence is merely an indication that some necessary precaution has been omitted.[19]

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[12] See Draper, *Phil. Mag.*, 9, 195 (1841).

[13] Ostwald's Klass., No. 152, 101; cf. Slater, *Phil. Mag.*, 5, 678 (1853); Goldberg, *Z. wiss. Phot.*, 4, 99 (1906).

[14] *Z. Elektrochem.*, 22, 202–206 (1916).

[15] *Pogg. Ann.*, 96, 373–394 (1855); 100, 43–88 (1857); 101, 235–263 (1857); 108, 193–273 (1859); Ostwald's Klass., Nos. 34 and 38; *Trans. Royal Soc. Lond.*, 381 (1887); *Phil. Trans.*, 146, 355 (1857); 146, 601 (1857); 148, 879 (1859).

[16] Beer, *Pogg. Ann.*, 86, 76 (1852). See Webster, *Phys. Rev.*, 4, 177 (1914); cf. Stark, *Physik.*, 9, 892 (1908).

[17] *Phys. Rev.*, 4. 177–194 (1914).

[18] *Loc. cit.*

Another phenomenon noticed in connection with the interaction of hydrogen and chlorine in the presence of light is the so-called "Budde effect," [20] which is a quick expansion of chlorine brought about by intensive lighting and thought to be independent of any heating effect, because the interposition of a screen of water between the light and chlorine has no effect on the results. Budde's explanation of the cause of reaction between chlorine and hydrogen in the presence of light is interesting, because it is one of the early suggestions concerning the dissociation of gases. The following is quoted from the work of Budde:[21] "Now it is known that in chlorine through insolation there is induced a higher degree of chemical activity. This fact might be accounted for in two ways: (1) by assuming that light increases the attraction between the atoms Cl of chlorine and X of the respective other body; (2) by assuming that light tends to resolve, or actually does resolve, the chlorine molecule into its atoms. Of these two hypotheses, the former does not appear very probable, the less so as in the action of light on silver chloride, for instance, we observe a direct severing of connection between Ag and Cl, while the latter, *à priori* at least, does not provoke any objections. . . . I assume that light in general diminishes the force uniting Cl with Cl, and that occasionally through the coöperation of light and internal motion (heat) a molecule, Cl_2, is actually split up into its constituents, Cl· and Cl′." Richardson [22] verified the work of Budde and describes the construction of a continuous recording actinometer based on the Budde effect. The apparatus consists of two bulbs, one filled with dry air and the other with chlorine, the bulbs being connected by a tube containing sulphuric acid. The apparatus is suspended from the beam of a balance, so that the flow of sulphuric acid from one bulb to the other produces a movement of the beam which is communicated by means of a lever to a pen and is recorded on a rotary drum. He eliminates the expansion due to heat by an ingenious arrangement. These observations were confirmed also by Recklinghausen[23] and Mellor,[24] who used moist but not dry chlorine. Others have found, however, that the Budde effect and the Draper effect—a sudden expansion followed by a return to original volume when a strong light "as a spark from a Leyden jar is momentarily flashed upon a mixture of chlorine and hydrogen"—though confirmed by Favre and Silberman, and Amato,[25] were due to impurities in the gas, and the effects were not obtained by Baker[26] when the pure gas was used. Shenstone,[27] like Baker, found no change in volume when light acted on pure dry chlorine. Bevan[28] showed that activity of the form of chlorine reported by Bunsen and Roscoe was attributable to the presence of water. Pringsheim[29] observed that, when heated and dried, gases exploded not so quickly as moist gases, but just as violently. Dixon and Harker as early as 1889[30] pointed out that the more carefully the mixture of gases was dried the greater was the intensity of light required to cause detonation in hydrogen chlorine mixtures, but that an electric spark always caused an explosion at once, no matter how carefully the gases were dried. These experimenters measured the rate of propagation of the detonation wave and showed it to be greater in dry than in moist gases, from which they conclude that moisture retards rather than accelerates the reaction. This phenomenon is surprising in view of the fact that there are innumerable reactions that apparently will not take place in the absence of moisture. As early as 1802, Mrs. Fulhame[31] called attention to the necessity of moistening gold salts before reducing them with hydrogen or by "phosphorated ether." A short while later Higgens[32] observed that dry hydrochloric acid did not act on calcium carbonate. According to Bigelow,[33] strictly dry silver chloride is hardly sensitive to light. A brief *résumé* of the early reports on these phenomena is given in the paper of Mellor and Russell,[34] who refer to Baker[35] for a complete list of later works on the phenomena.

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[19] Burgess and Chapman, *Chem. Soc. Lond. Trans.*, 89, 1399–1434 (1906); cf. Mellor, "Chemical Statics and Dynamics," London (1909).

[20] Budde, *Phil. Mag.*, 42 (4), 290–294 (1871).

[21] *Loc. cit.*

[22] *Phil. Mag.*, 277–284 (1891).

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[23] *Z. phys. Chem.*, 14, 494 (1894).

[24] *J. Chem. Soc.*, 1284 (1902).

[25] Cf. Mellor, *Loc. cit.*

[26] Brit. Assoc. Rept., 493 (1894).

[27] *J. Chem. Soc. Trans.*, 71, 471–488 (1907).

[28] *Proc. Roy. Soc.*, 72, 5 (1903).

[29] *Ann. Phys. Chem.*, 32, 422 (1887).

[30] "Manchester's Memoirs," 3, 118 (1889); 4, 1 (1890).

[31] Cf. Thompson, "A System of Chemistry," 2, 454 (1802).

Fabre and Silbermann[36] sought to find a heat change in illuminated chlorine absorbed by solution of potassium hydroxide. They reported a noticeable difference between the action of illuminated and unilluminated gas, and a greater amount of potassium chlorate formed by illuminated chlorine. These results were shown, however, to be false by Berthelot[37] and Mellor.[38] Later Mellor[39] showed that the Budde effect was due to the heating action of the absorbed rays. In a series of papers on the "Union of Hydrogen and Chlorine" Mellor[40] gives a review of previous work on many different phases of the subject and reports personal experiments. To follow these interesting researches would carry one too deeply into the subject for the immediate purposes of this paper, so that the following references are added as an aid to those who are particularly interested in this reaction:[41]

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[32] "Experiments and Observations on the Atomic Theory," 1814; cf. Mellor and Russell, *Loc. cit.*

[33] *Loc. cit.*, p. 368.

[34] *Loc. cit.*

[35] *Journ. Chem. Soc. Trans.*, 64, 611 (1894).

[36] *Ann. Ch. Ph.*, 37, 497 (1853).

[37] *Ann. Chem. Ph.*, 5, 322 (1876).

[38] *J. Chem. Soc.*, London, 81, 1280 (1902).

[39] *Loc. cit.*

[40] *J. Chem. Soc. Trans.*, 79, 216–238 (1901); 81, 1292–1301 (1902).

[41] Chapman and MacMahon, 'The Interaction of Hydrogen and Chlorine," *J. Chem. Soc.*, 95, 135–138; 959–964; 1717–1720 (1909); 97, 845–851 (1910); Sirk, "Hydrogen and Chlorine in Heating and Under the Influence of Light," *Z. physik. Chem.*, 61, 545 (1908); Bodenstein and Dux, "Photochemical Kinetics of Electrolytic Chlorine-Hydrogen Mixtures," *Z. physik. Chem.*, 85, 297–328 (1913); *Physik. Elektrochem.*, 19, 836–856 (1913); Taylor, "The Interaction of Hydrogen and Chlorine Under the Influence of Alpha Particles," *J. Am. Chem. Soc.*, 37, 24–38 (1915); *Ibid.*, 38, 280-285 (1916). Bodenstein, *Z. angew. Chem.*, 28 (3), 621 (1915).

First, the decomposition of hydrochloric acid.[42]

Second, the oxidation of hydrogen and sulphur dioxide and decomposition of ozone in the presence of chlorine and light.[43]

Third, the action of light on certain chlorine acids.[44]

Fourth, the decomposition of chlorine water.[45]

Fifth, the action of carbon monoxide on chlorine to form phosgene.[46]

Sixth, the substitution of chlorine in organic substances, of which the following are among the noteworthy:

(*a*) In methane.[47]
(*b*) In acetylene.[48]
(*c*) In benzene.[49]
(*d*) In toluene.[50]
(*e*) In xylol.[51]
(*f*) In mesitylene.[52]
(*g*) In acetylbenzol.[53]
(*h*) In chlorbenzol.[54]
(*i*) In tetra-butyl benzene and orth-butyl toluene.[55]
(*j*) In sulphobenzid.[56]
(*k*) In alcohol.[57]
(*l*) In methyl ether.[58]
(*m*) In hydrocarbons of the chain C_nH_{2n} and C_nH_{2n-2}.[59]
(*n*) In acetic acids.[60]
(*o*) In cinnamic acid.[61]
(*p*) In oils, fats, rosins, or paraffin.[62]
(*q*) In compounds contained in natural petroleums.[63]
(*r*) In compounds contained in natural gas.[64]
(*s*) In hydrocarbons.[65]

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[42] Coehn and Wassuljewa, *Ber.*, 42, 3183–3186 (1909); Berthelot and Gaudechon, *Compt. rend.*, 156, 889–892 (1913); Thiele, *Ber.*, 140, 4914 (1907).

[43] Weigert, *Ann. Phys.*, 24, 243–266 (1907).

[44] Pedler, *Proc. Chem. Soc.*, 79, 65–66 (1890).

[45] Wittwer, *Pogg. Ann.*, 94, 597 (1853); Bunsen and Roscoe, *Pogg. Ann.*, 96, 373–374 (1855); Wittwer, *Pogg. Ann.*, 95, 598 (1885); 86, 281 (1862); Billitzer, *Jahrb. Phot.*, 82–88 (1907); cf. also Kummell, *Z. Elektrochem.*, 17, 409–412 (1911); *Proc. Chem. Soc.*, 79, 65–66 (1890); Benrath and Tuchel, *Z. wiss. Phot.*, 13, 383–398 (1914); Milauer, *Z. physik. Chem.*, 86, 564–566 (1914); Dawson, *Z. wiss. Phot.*, 14, 213–215 (1914); Benrath, *Ibid.*, 14, 238 (1915); Stobbe, *Z. Ann. Chem.*, 21, 388 (1908).

[46] Chapman and Gee, *J. Chem. Soc.*, 99, 1726–1739 (1911); *Proceedings*, 27, 232–234; Davy, *Phil. Trans.*, 144 (1812); Cordier, *Monatsch.*, 21, 660 (1900); Dyson and Harden, *J. Chem. Soc. Trans.*, 83, 291 (1903); Wilderman, *Z. phys. Chem.*, 42, 257 (1903); Weigert, *Ann. Phys.*, 24, 55–57 (1907); 24, 243–266 (1907). Cohen and Becker, *Ber.*, 43, 130–133 (1910).

[47] Hofmann, *Lieb. Ann.*, 102; Baskerville, *J. Ind. Eng. Chem.*, 4, 216 (1912); Baskerville and Riedever, *J. Ind. Eng. Chem.*, 5, 5–8 (1913); see also *Proc. 8th Inter. Congress Applied Chemistry;* Philips, *Amer. Chem. Jour.*, 16, 362; Walter, German Patent 222,919, November 5, 1909.

[48] U. S. Patent 908,051, December 29, 1908.

[49] Faraday, *Ann. Chem. Phys.*, 30, 274; Mitscheruch, *Pogg. Ann. Phys. und Chem.*, 35 (5), 370–374 (1835); Slater, *Z. phys. Chem.*, 45, 5 (1903); *Ibid.*, 45, 540 (1903); Bancroft, *J. Phys. Chem.*, 12, 4 (1908); Luther and Goldberg, *Z. phys. Chem.*, 56, 43–56 (1906).

It was thought that a study of the formation of certain compounds of chlorine in the presence of artificial light, known to be accelerated by sunlight, would be of value. Chloracetic acid was the first compound selected.

CHLORINATION OF ACETIC ACID.

Chloracetic acid was discovered by Dumas[66] in 1839. After filling flasks with chlorine gas he added not more than nine decigrammes of crystallized acetic acid to each litre of chlorine gas. He stoppered the flasks and placed them so that they were exposed to the direct rays of the sun for a whole day. At the end of this time he found that a substance had been formed which had crystallized from the residue contained in several of the flasks and which by examination he proved to be a true chlorine substitution product of acetic acid.

It has been found that several substances, such as phosphorus and sulphur, greatly accelerate this reaction. A laboratory method for the preparation of chloracetic acid is given in Gatter-

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[50] Shramm, *Ber.*, 18, 606 (1885); Cohen, Dawson and Crosland, *J. Chem. Soc.*, 87, 1034–1037 (1905); Luther and Goldberg, *Z. phys. Chem.*, 56, 43–56 (1906); Schluederberg, *J. Phys. Chem.*, 12, 574–631 (1908); Bancroft, *J. Phys. Chem.*, 12, 420 (1908); Cohen, Dawson, Blackey and Woodmansey, *J. Chem. Soc.*, 97, 1623–1636 (1910).

[51] Luther and Goldberg, *Z. phys. Chem.*, 56, 43–56 (1906).

[52] Zadziewanowski and Schram, *Ber. Krakauer Akad. d. Wiss.*, 61 (1898).

[53] Zadziewanowski and Schram, *Ber. Krakauer Akad. d. Wiss.*, 61 (1898).

[54] Jungfleisch, *Z. Chem.*, 486 (1868).

[55] Salivill, *Bull. intern. acad. sci.*, Cracome A, 606–608 (1910).

[56] Matthews, *J. Chem. Soc.*, 61, 108.

[57] Schmidt, *J. Pract. Chem.* (2), 19, 393.

[58] Cahour, *Compt. rend.*, 23, 1070 (1846).

[59] Romer, *Lieb. Ann.*, 233, 172.

[60] Dumas, *Lieb. Ann. der Chem.*, 32, 101 (1839); *J. Pract. Chem.*, 17, 202; Luther and Goldberg, *loc. cit.*

[61] Nazarov, *J. Russ. Phys. Chem. Soc.*, 47, 943–955 (1915).

[62] Buchner, U. S. Patent 1,129,165, February 23, 1915.

[63] Tolloczko and Kling, *Abhandl. Krakauer Akad. Wissensch.*, 52, 295–306; *Ibid.*, 307–316.

[64] Baskerville and Riedever, *Proc. 8th Inter. Cong. Applied Chem.;* see also Baskerville, *J. Ind. Eng. Chem.*, 216 (1912); Phillips, *Ann. Chem. Jour.*, 16, 362.

[65] DuPont Nemours Powder Co., French Patent 453,406, January 21, 1913; Sparre and Masland, U. S. Patent 1,148,259 (1915).

[66] *Liebig's Ann. der Chemie*. 32, 101 (1839).

man's "Practical Methods of Organic Chemistry."[67] It has been found by experience that if the experiment there described is carried out with the apparatus placed in the direct rays of the sun for a full summer's day eighty grammes of chloracetic acid is obtained from one hundred grammes of original acetic acid. The yield is dependent upon the amount of sunlight and its intensity.

It is interesting to note, in passing, that Fay[68] found that acetic, propionic, and isobutyric acids were decomposed into hydrocarbons corresponding to the acids and carbon dioxide when acted on by light in the presence of uranium salts.

"In a letter to Goethe in 1811, Seebech intimated that a mixture of hydrogen and chlorine gases contained in a clear glass vessel detonated in the sunshine, whilst under dark-blue glass combination occurred without explosion in one minute, and under a dark-red glass the action took place very slowly or not at all."[69]

Bunsen and Roscoe[70] showed by chlorine-hydrogen mixture that several bands in the spectrum produced maximum effects. They found, further, that the action diminished toward the red end of the spectrum, and regularly decreased in proportion to the distance of the band from the ultraviolet end.

Morren[71] and Gernez[72] showed that in chlorine-filtered light no blue rays are present; and, as only those rays which are absorbed are active, this would indicate that the blue light would be the light which caused the reaction.

Schramm[73] obtained analogous results to those obtained by Bunsen and Roscoe in the action of light on bromine and toluene and ethyl benzol, etc.

Eder,[74] in his summary of observations on the "Chemical Action of the Solar Spectrum," points out that light of every color, from the ultraviolet to the infra-red, can cause chemical action. He calls attention to the fact that each color can have an oxidizing or reducing effect, dependent on the nature of the light-sensitive substance. He, however, generalizes the oxidation and reduction effects of different wave-lengths by saying that red light usually has a reducing effect. He cites, as an example of reducing action by red light on metallic compounds, the use of sliver salts in the photography of spectra. He also points out that blue and violet lights have the most effect on compounds of the metalloids, giving as an example hydrogen and chlorine mixtures.

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[67] Page 139 (1909).

[68] *Am. Chem. Jour.*, 18, 269-289 (1896).

[69] Mellor, *loc. cit.*

[70] *Pogg. Ann.*, 108, 270 (1859).

[71] *Compt. rend.*, 376 (1869).

[72] *Compt. rend.*, 660 (1872).

[73] *Monatschafte*, 300 (1889).

[74] "Handbuch der Photographie," Ed. 2, 1, 180 (1892).

In the report of their experiments in connection with work in the substitution products of chlorine and natural gas, Baskerville and Riedever[75] found that blue light from a projection lantern was the most effective light obtainable for the purpose, and, as the laboratory method for preparing chloracetic acid, referred to above, had been successfully carried out in glass apparatus, thus excluding the ultraviolet light, it was thought advisable to attempt to make chloracetic acid, using light from a projection lantern. This will be referred to later.

Since the classical work of Hertz,[76] in conclusion of which he says:

> "We have represented the phenomena investigated by us as rays of electric force. We may, in conclusion, regard them as light rays of very great wave-length. To me at least the experiments described seem eminently fitted to remove all doubt as to the identity of light, radiant heat, and electrodynamic wave-motion. I believe that we shall now with more confidence avail ourselves of the advantages which the assumption of this identity offers, both in the domain of optics and electricity,"

one may accept as a working hypothesis that the forms of radiant energy, radiant heat, light, and electricity, are similar in all essential respects excepting wave-length. Different effects are produced by different wave-lengths. All experimental work tends to prove that radiant energy is due to electrons in motion, and it is important to keep in mind that when radiant energy impinges on an object it may be partly or totally reflected, in part or totally absorbed, in part or totally converted into other forms of energy, or may partly or entirely pass through unaltered.

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[75] *Loc. cit.*

[76] "On Rays of Electric Force." *Phil. Mag.*, 27, 289–298 (1889) (translated from *Sitzungsb. der Akad. der Wiss. Berlin,* December 13, 1888).

That light exerts pressure has been definitely proved.[77] This pressure is an entirely negligible quantity in all our measurements, but on exceedingly small, light objects—for instance, molecules of a highly rarefied gas—it may not be negligible.[78]

Bragg[79] points out that if we reason from the ideas of Planck, Einstein, and others we are led to the thought that light energy is in separate quanta, the shorter the wave-length, the more energy in the quanta. He discusses the question as still open, there being "still something in the corpuscular theory of light,"[80] as light resembles so closely the X-rays, which have much evidence to show them to be due to corpuscles. He points out that Huyghens's other theory was accepted because (1) it was not believed that matter could travel with the velocity of light, but now it has been demonstrated that the alpha particles which are conceded to be material move with about the same velocity, and (2) it was believed that streams of matter could not interpenetrate each other, and now it has been demonstrated that streams can pass each other and that no matter is impenetrable. Huyghens's wave-front, however, still explains reflection and refraction.

Bigelow[81] paraphrases a famous statement of Kekulé as follows:

> "Whether radiant energy be electrons or not, this much is certain, that, granting it to be electrons, it would appear as it now does."

Smiths and Aten[82] made a systematic study of the similarity between the action of light and the silent electric discharge in the formation and decomposition of a number of hydrogen compounds, including hydrochloric acid. When light was employed the gases were led through a thin-walled quartz tube which was exposed to the rays from a quartz mercury lamp. For study of the effect of a silent electric discharge an ordinary ozonizer was used, the current for which was supplied by an induction coil and condensers capable of giving a one-centimetre spark. They found that when water was present in the gases the silent electric discharge uniformly produced combination or decomposition in all the cases tried; with light the reactions were not so universally proved. When the materials were dry it was found that the reactions were often not obtained on repeated trials, but later very decided reactions were evident.

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[77] Bigelow, "Theoretical and Physical Chemistry," p. 503 (1914); see also Morris, *Sci. Ass. Sup.*, 76, 18–19 (1913).

[78] *Nature*, 90, 558 (1913).

[79] Cf. Arrhenius, "Das Wenden der Welten."

[80] See also Thompson, *Proc. Camb. Phil. Soc.*, 14, 417, on the "Ionization of Cases by Ultraviolet Light," and on the evidence as to the structure of light afforded by its electrical effects.

[81] "Theoretical and Physical Chemistry," New York, 1914, p. 502.

[82] *Z. Elektrochem.*, 16, 264–267 (1910).

These results show a similarity in the action of light and silent electric discharge in nearly all the cases tried. These writers point out that a failure by them to decompose the water by the light or electric discharge was not surprising because of the high temperature necessary for the dissociation of water. In this connection it may be mentioned that Thiele [83] has shown that oxygen and hydrogen may be caused to unite by the aid of ultraviolet light.

The discussion of Smiths and Aten as to the conditions under which the reactions take place is very interesting. They state that if light or electric energy is added to a system which is in equilibrium when in the dark or is in thermochemical equilibrium, and the system is sensitive to that form of energy, a new equilibrium is established which differs from the old in that it is thermochemically metastable, since it always agrees with the equilibrium in the dark but not with the electrochemical equilibrium of higher temperatures. They discussed different photo- and electrochemical equilibriums, and the photochemical dissociation equilibrium of hydrogen and chlorine was predicted.

The hypothesis of Smiths and Aten has been confirmed by Coehn,[84] who found that this equilibrium can be demonstrated so conveniently in the reaction between hydrogen and chlorine that the dissociation of hydrochloric acid by light can be demonstrated by a lecture experiment.

Smiths and Aten [85] state that one of them published a series of experiments [86] which proved the above-mentioned law that photo- and electrochemical equilibriums agree with purely thermochemical equilibrium of higher temperature.[87]

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[83] *Ber.*, 40, 4914 (1907).

[84] *Ber.*, 42, 3183 (1909).

[85] *Z. Elektrochem.*, 16, 264–267 (1910).

[86] *Koninkl. Akad. von Wetenschappen Amsterdam.* October 30. 1909. p. 386.

They call attention to the rise in potential between electrodes at the ends of a gas column when the column is acted on by light. This phenomenon occurring at constant temperature would furnish evidence of an increase of the inner energy of the molecule. Both the inner and outer energy of the molecule would increase with the temperature.

Recognizing that the inner energy is the principal factor of a chemical reaction, they base their hypothesis on the fact that the absorption of electrical energy and light energy even at ordinary temperatures brings about equilibriums which are also found by addition of heat energy, although in that case at much higher temperatures.

They point out that this hypothesis leads to an explanation of the enormous velocity of reaction caused by light and electricity because the photo- and electro-equilibrium at the usual temperature agrees with thermic equilibrium of much higher temperature. They also give the conditions under which the law of mass action is applicable to photo- and electrochemical equilibrium. They say that it is applicable when the energy is in such an amount that it has an effect without any apparent diminution of its intensity; *i.e.,* when the system is homogeneous. When, however, it is less intense, then the decrease in energy is plainly apparent; the condition is different from stratum to stratum, and the system is non-homogeneous and the law is not applicable.

Berthelot and Gaudechon[88] performed experiments on the dissociation of gaseous compounds by light; the compounds used including hydrochloric acid, hydrobromic acid, and hydroiodic acid. They showed that in photochemical reactions frequency of vibration plays the same rôle as does temperature in heat reactions, and that for compounds of the same group the stability of hydrogen compounds exposed to light decreased with the increase of molecular weight, paralleling the thermal phenomena. Where only a very elevated temperature caused appreciable dissociation, only the extreme ultraviolet rays caused similar dissociation. This very general statement concerning the similarity in action of temperature and frequency of vibration must, however, be considered carefully so that one will not be led into reasoning that light and heat action are identical, which, of course, is not the case.

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[87] See also Berthelot, *loc. cit.*

[88] *Compt. rend.,* 156, 889–892 (1913).

Goldberg[89] pointed out that the temperature coefficient of reaction velocities of all light-sensitive reactions which had been observed was very small.

Nazarov[90] showed by experiment, in which he made observation on the effect of the addition of chlorine to cinomonic acid in the dark and in the light, that the temperature coefficient of photochemical reactions is approximately such as was to be expected, since photochemical reactions in their initial stages are supposed to be independent of the temperature. This is indeed a most interesting observation, because the chemist is accustomed to consider that no chemical change proceeds at a definite rate, regardless of temperature, with the exception, perhaps, of those taking place in the radio-active elements. Keeping always in mind the fact that a chemical reaction can take place only when the equilibrium between energy of different degrees of intensity becomes unstable, and that this is usually brought about by some apparently external cause, the above considerations impress one with the idea that the action of light in producing the equilibrium of energy which is indicated by the great law "that the energy of the universe tends toward a constant" is a greater factor than has usually been recognized.

Burgess and Chapman[91] have demonstrated by experiments on hydrogen-chlorine mixtures that chlorine can be made active by heat as well as by light. They note the curious fact that the behavior of dilute solutions of chlorine differs from that of more concentrated solutions in that the weak solutions gain considerably in acivity on simply being kept in the dark at ordinary temperatures. In the conclusion of their paper on the "Interaction of Chlorine and Hydrogen" they offer the following suggestion to explain the action of light on the hydrogen-chlorine mixture:

"The light which falls on the moist mixture of chlorine and hydrogen is absorbed, in the first instance, by the colored component (namely, the chlorine), and after it is absorbed it is degraded into heat. During the process of degradation the energy passes through various forms. Now it is conceivable that the distribution of the various kinds of vibration of which the degrading energy is composed will, in certain cases, depend largely on the presence in the system of even small quantities of foreign bodies. A difference in the rate of chemical change might clearly be expected as a result of a marked difference in the character of the energy through which the light passes as it is transformed into heat. Whether the quality of the energy can vary to the degree required by this hypothesis, according as certain impurities are present or not, and whether this variation can be regarded as the chief determining character of the change, is at present purely a matter of conjecture, and awaits experimental confirmation."

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[89] *Z. phys. Chem.*, 41, 1.

[90] *J. Russ. Phys. Chem. Soc.*, 47. 943–955 (1915).

[91] *Loc. cit.*

According to Lenard,[92] there are three kinds of effects produced when ultraviolet light acts on a gas:

1. "The gas may conduct electricity, owing to the formation of positive and negative ions.[93]

2. "Condensation nuclei may be formed devoid of electric charge.[94]

3. "Chemical molecular change may take place; as, for example, the action of ultraviolet rays on oxygen with the formation of ozone."

All of these reactions are due to the action of the periodic electric forces on the molecules of the gas. Therefore this classification of the kinds of effect produced by ultraviolet light may also apply to effects produced by radiant heat, light, or electricity.

Thomson[95] has shown that when an electric current passes through chlorine, chlorine occurs as Cl, Cl_2, $Cl++$, $Cl+$, $Cl-$; that is, neutral atomic chlorine, neutral molecular chlorine, atomic chlorine carrying two positive charges, atomic chlorine carrying one positive charge, and atomic chlorine carrying one negative charge.

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[92] Lenard and Wolf, *Ann. Phys. Chem.*, 3 (1899); *Ann. Phys.*, 1 and 3 (1900); see also Lenard and Ramsauer, *Trans. Heidelberg Acad.*, August 2, 1910; August 4, 1911, five parts.

[93] Thompson, "On the Ionization of Gases by Ultraviolet Light, etc.," *Proc. Camb. Phil. Soc.*, 14, 417; Steubing, "Ionization of Gases by Means of Light" (gives summary and bibliography), *Jahrb. Radioakt. Elektron*, 9, 111–137.

[94] Cf. Wilson, *Phil. Trans.*, 192 (1898); 198, 276 (1897); Bevan, *Proc. Roy. Soc.*, 72, 5 (1903); Burgess and Chapman, *loc. cit.*; Wigert, *Ann. Physik.*, 24, 243–266 (1907); Saltmarsh, *Proc. Phil. Soc. London*, 27, 357–369 (1915).

[95] Thomson, *Chem. News*, 103, 265–265 (1911).

Townsend,[96] in his paper on "The Electrical Properties of Freshly Manufactured Gases," says that chlorine prepared by electrolysis had a small negative charge, and that the charge on hydrogen varied from positive at first, when a new electrode was used, to a minus charge of definite value after use. An old electrode was found to give negatively charged hydrogen.

Shenstone,[97] after an experiment in which he attempted to form a compound similar to ozone, concludes that highly purified chlorine remains almost unaffected by the "ionization discharge."

Ludlam[98] conducted a series of experiments to show the nature of the action of ultraviolet light on chlorine. He states in his conclusion that pure chlorine is not ionized and that it does not form condensation nuclei, and, further, that chlorine in considerable quantities destroys the ions and nuclei otherwise found in the air.

Thompson[99] found no free-charged ions to be present during the combination of hydrogen and chlorine under the influence of light, and, further, that artificial production of free ions *(i.e.,* by Röntgen rays and radiation from thorium in the mixed gases) did not affect the rate of their combination. It may be mentioned, in passing, that probably the credit of being the first to find quantitative evidence to support the idea that a close relationship exists between ionization of a gas and chemical reactions induced in it by radio-active influence should be given to Lind.[100]

An interesting theory of photochemical reaction velocities has been advanced by Bodenstein.[101] He regards the initial absorption process in any photochemical change as a photo-electric effect. The molecule is ruptured at the expense of the absorbed light energy into a positive radical—an atom, or, with more complex substances, a molecule, with a free valence and a free electron. He believes that both portions may lead to chemical reaction, the positive radicals because they are chemically exceedingly active, and the electrons because they may attach themselves to molecules and so activate them that they take part in the chemical change. Bodenstein classifies light reactions into primary light reactions, in which the positive radicals enter into the combination, and secondary light reactions in which the molecules activated by the electrons take part in the reaction; the electrons, after the reaction has occurred, being again free to attach themselves to and activate other molecules.

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[96] *Pro. Cambr. Phil. Soc.,* 9, 345–371 (1897), and *Phil. Mag.,* 45, 125 (1898).

[97] *J. Chem. Soc. Tran., London,* 71, 486 (1897).

[98] *Phil. Mag.,* 23, 757–772 (1912).

[99] Thompson, *Proc. Camb. Phil. Soc.,* 11, 90–91 (1901).

[100] Lind, *J. Phys. Chem.,* 16, 564 (1912).

[101] Bodenstein, *Z. physik. Chem.,* 85, 330 (1913).

Commenting on this theory of Bodenstein's, Taylor[102] points out its application to all such chemical reactions that are effected under the influence of other forms of energy, provided that under such influence the rupture of the molecule with the formation of free electrons may be postulated. He later states that "the hypothesis originally put forward by Bodenstein to account for the kinetics of the photochemical reaction covers equally well the facts obtained from this radio-active study."

Taylor, following closely the ideas of Bodenstein, outlines the processes which are supposed to take place when an alpha particle passes through a mixture of hydrogen and chlorine. In this outline he assumes ionization and decomposition of the chlorine molecule into positively charged radicals and electrons.

Ludlam [103] shows that chlorine does not easily lose electrons, and says that this is what might be expected because of its electronegative character; affinity for negative electricity being a characteristic of electronegative elements. He considers hydrogen as being on the borderland, taking its position among the noble metals, by nature of its electrochemical properties. It is, however, more distinctly positive than copper, even at atmospheric pressure. Ludlam offers as an explanation of the action between hydrogen and chlorine the possibility that an atom of hydrogen under the influence of light emits an electron, which immediately attaches itself to an atom of chlorine, chemical combination taking place. In considering this theory it must be kept in mind that there is much evidence to show that a reaction takes place when the chlorine alone is acted on by light and subsequently led into the presence of hydrogen. Lenard and Ramsauer [104] suggest that the light splits up the chlorine molecules into two neutral atoms. It was pointed out that traces of foreign matter appear necessary for the ionization of gases and for their chemical combination, and yet actual liberation of electrons for a measurable period of time does not appear to be a precursor of gaseous combination.

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[102] *Loc. cit.*

[103] *Loc. cit.*

[104] *Loc. cit.*

Vernon[105] found that the silent electric discharge brought about a slight increase in volume in chlorine or a mixture of chlorine and bromine, which was accounted for by the heat effect on the gas.

Kellner, in the same year (1891), took out a patent,[106] in which he claimed to increase the bleaching power of chlorine by means of an electric discharge. For this purpose Barmemores has taken out a patent[107] in which he describes an apparatus for applying the principle of increasing the bleaching action of chlorine by the same means.

Kellner,[108] in a paper, "On the Conduct of Bromine Under the Influence of a High-frequency Discharge," reports finding a decided change in bromine, and states without elaboration that chlorine under the action of an electric discharge showed properties different from the ordinary chlorine, and that it combined in the dark with acetic acid.

According to Mellor,[109] chlorine acted on by light first and then passed into hydrogen does not form hydrochloric acid. Mellor and Russell[110] carefully prepared pure dry chlorine and reported experiments on its action on hydrogen in the presence of an electric spark, heat, and sunlight. They conclude, from their results, that the electric spark causes explosion in either moist or dry chlorine-hydrogen mixture, and because the combination was found to be complete they conclude that the action was propagated through the whole mass. Neither heat nor sunlight caused explosion in the dried gas combination; when combustion occurred at all it occurred slowly and incompletely, and was not transmitted through the whole of the gas, as in the case where the electric discharge was used.

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[105] *Chem. News,* 63, 67 (1891).

[106] E. P. 22,438, December 23, 1891; D. F. R. 67,980, February 5, 1892.

[107] Ost. P. 11,180, October 15, 1902.

[108] *Z. Elektrochem.,* 8, 500–504 (1902).

[109] *Loc. cit.*

[110] *J. Chem. Soc. Tran.,* 81, 1272–1280 (1902).

Briner and Durand[111] found that there was no polymeric variety of chlorine formed when chlorine was acted on by the electric discharges. They express the opinion that the observations of Kellner, who reported an active form of chlorine, were probably erroneous; the active form "being in reality attributable to the formation of ozone or oxides of chlorine in the impure chlorine used by Kellner."

Kummell[112] states that there is no molecular change when chlorine is acted on by light, and, after referring to previous work on the subject,[113] proceeds with experiments showing that dry chlorine acted as did nitrogen, hydrogen, carbon monoxide, and oxygen, though moist chlorine showed an apparent ionization in the dark, which was greatly accelerated by light. Kummell showed that this was due to the formation of hydrochloric acid from water and chlorine. A rapid discharge of the electroscope used to measure the charge was obtained when the hydrochloric acid content was increased, but no discharge resulted when 20 to 40 per cent. of oxygen was mixed with moist chlorine, in order if possible to bring about a reversal of the reaction.

Le Blanc and Valmer,[114] in answer to the question, "Does ionization of chlorine 'knall gas' commence on exposure to light?" found no such ionization, and they suggest that the values found by Kummell were the result of defective insulation. They found, however, that Röntgen rays caused a chemical reaction to take place.

It may also be noted that Melander,[115] in reporting their researches on the rate of reaction between chlorine and hydrogen when heated, stated that chlorine heated previous to the reaction with hydrogen gave no evidence of increased activity. They noted that the reaction was bimolecular and increased by addition of sulphur dioxide or sulphuric acid.

(*To be continued.*)

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[111] *Z. Elektrochem.*, 14, 706–707 (1908).

[112] *Z. Elektrochem.*, 17, 409–412 (1911).

[113] Wobig and Kummell, *Z. Elektrochem.*, 15, 252–254 (1909); Budde, *Ber.*, 459 (1871); Melloni, *Jahresber. d. Chem.*, 180 (1871), and Pringsheim, *Ann. d. Physik. und Chem.*, N. F. 32, 384 (1887).

[114] *Z. Elektrochem.*, 20, 494, 497 (1914).

[115] *Archiv. Kemi. Min. Geol.*, 5, 22 (1914).

THE METALLURGY OF TITANIUM.*

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In Open-hearth Practice.—In acid open-hearth work the same general procedure is followed, except that the ladle should be held longer, usually about five to ten minutes, in order that the impurities scavenged out by the titanium may have time to pass out into the slag. There appears to be no reason for this other than the experience of practical operators. In case the titanium alloy is added in the furnace, great care must be observed to prevent its contact with the slag, and it should be as quickly and as thoroughly rabbled into the bath as possible. The steel should be tapped at once, as delay will but undo the work already performed by the alloy. In basic open-hearth practice, usually it appears expedient to add about 75 per cent. of the ferro-manganese in the furnace and the rest in the ladle with the ferro-silicon. The addition of these ferro-alloys to the ladle should be rapidly followed with the titanium alloy addition, observing the precautions already stated for keeping it from contact with the slag. Charles V. Slocum urges that the titanium alloy should not be pre-heated before adding to a bath of steel or iron. Doctor Moldenke, on the other hand, speaks of the " necessity " of heating the alloy red hot before using it. Practical experience shows that it does the work cold as well as hot, and the general tendency is to use it cold. However that may be, it would appear that heating the alloy, or using it liquid, as is the coming European practice with ferro-manganese, would facilitate its readier incorporation into the metal. As to whether it should be used in conjunction with aluminum there is no agreement among metallurgists. The evidence seems to favor those who claim that titanium should never be used in conjunction with aluminum. The size of pieces of alloy to be added in open-hearth heats depends on the size of the heats; in general, the larger the heat tonnage, the larger the pieces of alloy may be. Thus for heats over 25 tons pieces screened through a 0.75-inch screen are recommended.

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* Continued from page 508, vol 184, October issue.

In Electric Furnace Practice.—Of all the appliances used for the production of liquid steel, the electric furnace admittedly does give a thoroughly deoxidized metal. At any rate, whether the steel has been thoroughly deoxidized in the furnace or not, it will be somewhat reoxidized during tapping into the ladle, and slag will become entangled with the metal during this period. In case the electric furnace is acid-lined instead of basic, the operation is simply one of melting, and deoxidation must be secured. For electric-furnace practice, whether acid or basic, it may be well to add titanium alloy during the tapping of the steel into the ladle in the same way as in Bessemer and open-hearth work; and, as usual, the steel should be held for about five or more minutes to allow the reaction to take place and to permit the entrained slags and oxides to rise to the surface. The modern metallographic microscope has shown that titanium-treated steels contain included particles of a pinkish substance, now identified as titanium nitride crystals, so that it is extremely doubtful whether, under the conditions of the present fast practice, this compound finds its way into the slag at all. Regardless of that, its presence appears to do the steel no particular harm.

In Crucible Practice.—In the crucible process the best results have been secured by adding the titanium alloy to the pots before they are removed from the furnace and allowing time for the chemical reactions to take place before teeming.

Effect of Titanium on Cementation.—The work of Leon Guillet[71] indicates that it is proved that the substances which retard cementation are those which are found in solution in the iron, as Ni, Ti, Si, and Al, and that the substances which accelerate cementation are those which seem to exist in the state of double carbides, substituting a part of the iron of the cementite, as Mn, Cr, W, and Mo. He has constructed Table IV from data secured from experiment.

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[71] Guillet, Leon, "La cementation des aciers au carbone et des aciers speciaux," *Memoires et compte rendu des travaux de la Société des Ingénieurs Civils de France,* series vi, No. 2, February, 1904.

TABLE IV.

Proportion of foreign metal	Velocity of penetration in tenths of a millimetre	Proportion of foreign metal	Velocity of penetration in tenths of a millimetre
2% Ni	7	2% Mo	11
5% Ni	5	1% Ti	8
0.5% Mn	11	2% Ti	7
1.0% Mn.	12	0.5% Si	6
1.0% Cr.	10	1.0% Si	5
2.0% Cr.	11	2.0% Si	4
0.5% W.	9	5.0% Si	0*
1.0% W	9	1.0% Al	4
2.0% W	12	3.0% Al	2
1.0% Mo	9		

* No cementation

NOTE.—Under the same conditions a carbon steel showed a penetration of 0.90 mm.

Titanium in Rail Steel.—The question of the manufacture of sound homogeneous steel for rail production is one that has had a great deal of attention by metallurgists, maintenance engineers, and others interested in the subject. A great deal of data has been secured relative to rail wear, and many lengthy reports have been formulated on the subject. Among others prominently connected with the rail question have been Hunt, Dudley, Wickhorst, and Waterhouse, who have contributed to the advancing technique of rail manufacture in no small measure. In this country practically all rails of heavier section for main-line track are now produced from ingots cast from basic open-hearth steel. Acid-Bessemer rails fell into disrepute some time ago. On curves manganese-steel rails have found some favor, as their wearing qualities will stand the higher cost; for straight-away track manganese steel is prohibitively costly. It has just been said that most rails are now made from basic open-hearth steel, and it may be more completely stated that the open-hearth is used in connection with duplexing practice; *i.e.*, a combination of the Bessemer and open-hearth furnaces, where the steel is desiliconized and partly decarburized in the acid-Bessemer converter, and then finished in a basic open-hearth furnace. Roughly, open-hearth steel-rail specifications call for rails within this chemical composition: carbon, 0.55 to 0.85 per cent.; manganese, 0.60 to 0.90; silicon, less than 0.25; and phosphorus, less than 0.04 to 0.06 per cent. More elaborate specifications have been drawn up by the rail committees of the American Society for Testing Materials and of the American Railway Engineering Association, but these need not be further mentioned in this place.

Segregation in Rail Steel.—Segregation is one of the most important questions before the rail-steel maker. According to the now well-known selective freezing of certain molten alloys, and in this case steel, the upper-central part of a steel ingot usually shows the segregation of carbon, phosphorus, and sulphur. In all commercial practice the bulk of the ingot must be used, and it appears to be a hide-bound attitude that calls for a definite percentage of discard as crop from the top of the rolled ingot. Gathman tops and other appliances for keeping the tops hot or for raising the pipe up into the head presuppose that the steel is bad to start with. The production of sound homogeneous steel at the outset, before pouring, appears to be a *desideratum,* as recognized of late by W. C. Cushing.[72] The usual discard of 9 to 10 per cent. or more may not entirely eliminate the segregated portion, although it may crop off the pipe if there is one. George B. Waterhouse[73] shows the results of a number of experiments conducted on segregation in acid Bessemer-rail steel. A comparison was made of ordinary carbon steel ingots and steel ingots treated with 0.25 per cent. by weight of titanium in the form of a ferro-alloy. Very briefly, his results point out that there is much less sulphur segregation in titanium-treated steel than in ordinary steel, and the same thing applies to the segregation of phosphorus and carbon. The use of the alloy brought about a greater uniformity in the steel and, on the whole, lessened the segregation. The photographs in Figs. 9 and 10 are of an ordinary and a titanium-treated ingot. The most marked feature is the increased soundness of the titanium-treated metal because of the concentration of the blowholes into the pipe cavity. The use of aluminum is condemned by some railroad engineers because of the fact that the product of the reaction, viz., alumina, is highly infusible and remains in occluded form in the metal.

As previously pointed out, a great deal of data has been gathered relative to the rail question, and in view of this it appears to be somewhat of an idle ceremony to attempt to recast the writings in this short work. As Professor Richards aptly remarks:[74] "A. J. Rossi and The Titanium Alloys Manufacturing

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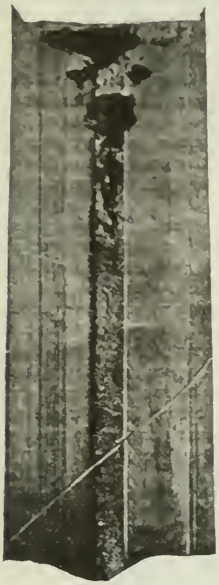
[72] Engineer Maintenance of Way, Pennsylvania Lines.

[73] Waterhouse, George B., "The Influence of Titanium on Segregation in Bessemer-rail Steel," A. S. T. M. meeting, Atlantic City, June–July, 1910.

[74] Richards, Joseph W., "The Metallurgy of the Rarer Metals," *Met. and Chem. Eng.,* July 1, 1916, vol. xv, No. 1, p. 26.

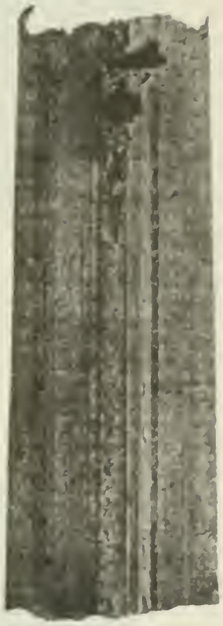
Company are the alpha and omega of the titanium industry. . . . . A finely written booklet of over 100 pages . . . tells the whole story, so why rehearse it here?" The series of booklets entitled "Rail Reports," issued by the same company, gives quite complete account of the function of titanium in the metallurgy of rail steel. It will suffice, therefore, to point out very briefly the marked improvement in rail steel effected by the use of titanium. Microscopic examination of steel treated with ferro-carbon titanium and rolled into rails and corresponding steel not so treated gave the results illustrated in the photomicrographs[75] in Figs. 11 to 16. The untreated steel shows an extremely coarse grain, indicating that the metal had been rolled very hot; it shows also a thick ferrite network and much decarburization in the flange of the rail. The treated rail contains only traces of ferrite, except at the surface, and is unsegregated.

FIG. 9.



Ordinary steel ingot. (After Waterhouse.)

FIG. 10.



Titanium steel ingot. (After Waterhouse.)

Titanium was first used in this country in November, 1907, in a heat of Bessemer steel, under the direction of S. S. Martin, at the works of the Maryland Steel Company. At the first trial

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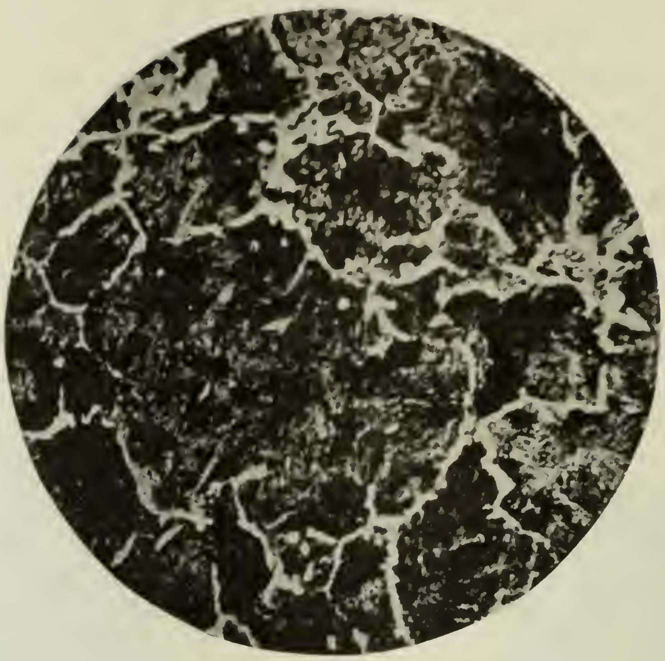
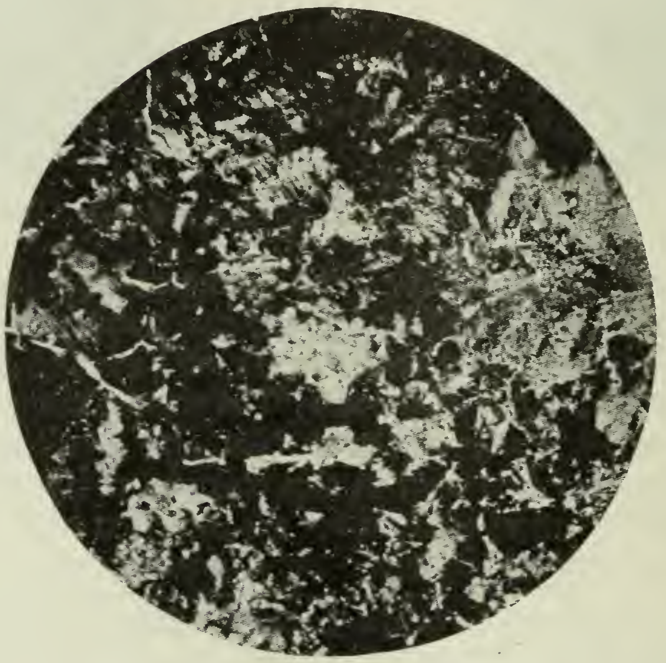
[75] Permission of George M. Comstock, The Titanium Alloys Manufacturing Company, Niagara Falls, N. Y., Rail Reports, Bull. No. 7, *Open Hearth*, 1914, p. 29.

FIG. 11.



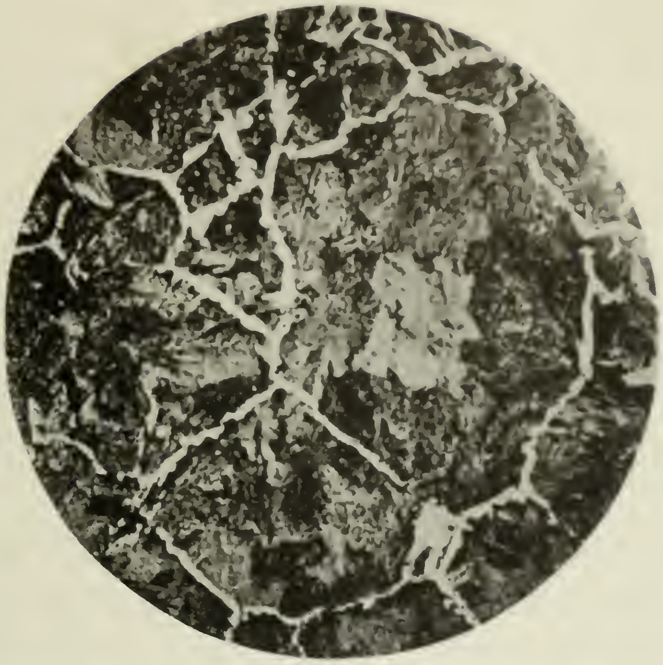
Section of untreated steel rail from top of head; etched to darken pearlite, leaving ferrite white. × 100 diameters. (After Comstock.)

FIG. 12.



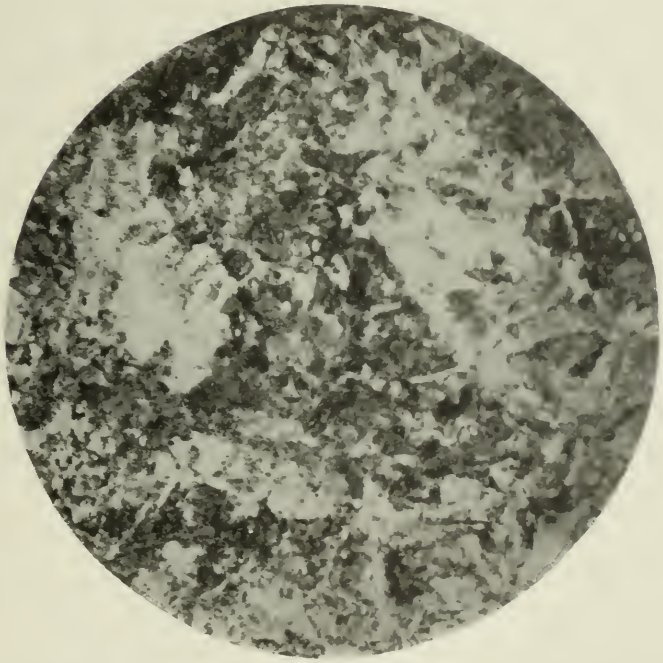
Section of treated steel rail from top of head; etched to darken pearlite, leaving ferrite white. × 100 diameters. (After Comstock.)

FIG. 13.



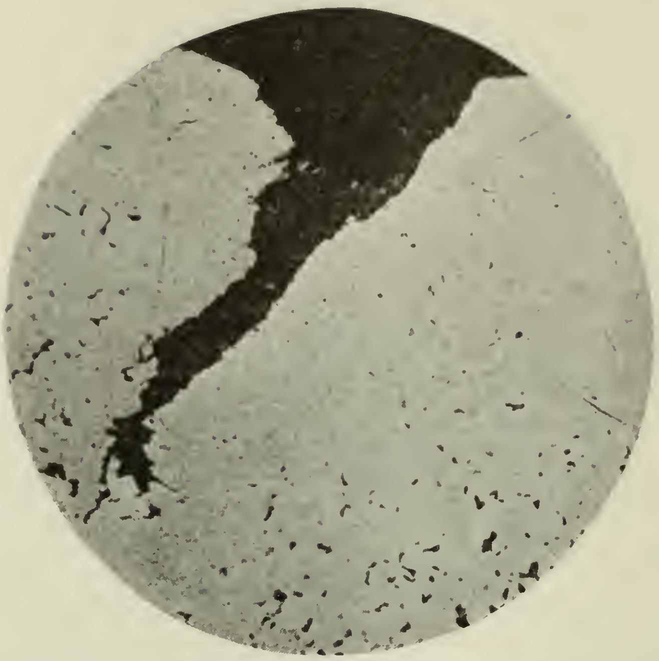
Section of untreated steel rail from web; etched to darken pearlite, leaving ferrite white. × 100 diameters. (After Comstock.)

FIG. 14.



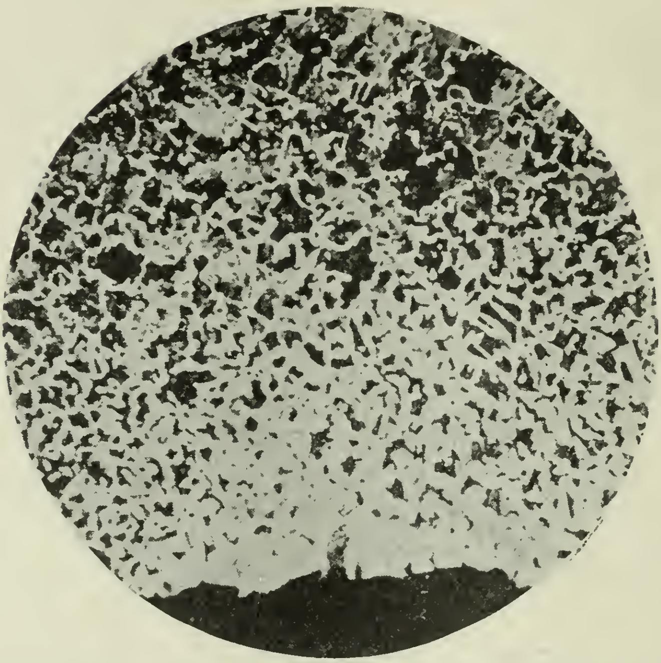
Section of treated steel rail from web; etched to darken pearlite, leaving ferrite white. × 100 diameters. After Comstock.)

FIG. 15.



Section of untreated steel rail from flange; etched to darken pearlite, leaving ferrite white. × 100 diameters. (After Comstock.)

FIG. 16.



Section of treated steel rail from flange; etched to darken pearlite, leaving ferrite white. × 100 diameters. (After Comstock.)

the steel showed such improvement that succeeding trials were made shortly after, which developed the remarkable features now so well known. Very exhaustive tests were made at the Lackawanna Steel Company's works in 1908, under the direction of a railroad engineer. The results of these tests and the experience of succeeding years endorse the merits of the titanium alloys for rail-steel manufacture. In short, the beneficial effects of the titanium treatment from the standpoint of the rail user are: (1) Increased rail life of from 200 to 400 per cent.; (2) tougher rails under the drop test; (3) strong steel; and (4) less flaking off of the metal in the head.

Titanium in Pipe Steel.—As in the metallurgy of liquid steel for the manufacture of other semi-finished products, titanium finds employment in steel to be used for pipe or tube production. What has been said elsewhere concerning the desirability of producing sound, homogeneous ingots for rolling into shapes applies here. Both pipe and tube (the two terms are used somewhat interchangeably, although the technical distinction between pipe and tube is that tubes are rated according to the outside diameter, and pipes according to the inside diameter) are made from wrought iron and steel by either lap welding or butt welding. Lap-welded pipe is made from scarfed skelp usually, and butt-welded pipe from grooved skelp, so that there will be avoided the excess of metal at the seam when otherwise no provision is made for that purpose. At times the presence of oxides and slag will make the welding of pipe or tube difficult, and such a product may be rejected as defective.

Titanium in Steel Castings.—The manufacture of steel castings, whether by the acid or basic open-hearth, the Bessemer or Tropenas converter, or in electric furnaces or crucible pots, presents certain inherent difficulties not found in the production of ingots for rolling. The reason for this lies mainly in the fact that the castings represent finished products as such, excepting, of course, the usual annealing, sand blasting, and other cleaning which they receive. Design of castings and expert pattern shop practice play an intimate part in good casting procedure, so that the problem is not a metallurgical one alone. Cracks and blowholes are common annoyances. The reason for the occurrences of cracks in steel castings is a question relative to which there has been much debate and little satisfactory information. Sulphur is commonly blamed for the presence of cracks, as well as red shortness. Blowholes are usually attributed to the escape of dissolved gases during solidification, which are pent up in the metal at freezing. Irrespective of the causes of unsoundness of steel castings, the production of a uniform product free from defects is a *desideratum*. Since the use of titanium thoroughly deoxidizes molten metal, its employment in steel casting practice would appear to aid in the production of good steel or even make good steel better.[76] W. A. Janssen carried on some experiments with the object in view of conserving his manganese supply by substituting a titanium alloy in part for ferro-manganese in making steel castings. This probably is the first well-defined attempt in that direction other than the use of spiegeleisen by some makers in the past year for the same purpose.[77] In any event, the use of a titanium alloy in steel casting manufacture is no longer a new procedure, but rather must be regarded as a necessity to overcome the vagaries of modern practice. The photomicrographs in Figs. 17 and 18 indicate the scavenging action of titanium on steel, the slag particles being noticeably smaller in the titanium-treated metal than in the plain untreated steel. The photograph illustrated in Fig. 19 shows a type of steel casting treated with carbon-free ferro-titanium.

Titanium in Forging Steels.—Forging steels (*i.e.*, steel produced in the semi-finished forms of blooms, billets, or other shapes for treatment under the hammer) are made in a wide range of analyses, but usually within the limits of from 0.10 to 1.25 per cent. C. In spite of the fact that sound, homogeneous steel may be made, it so happens that ill-advised hammer operation will give rise to a poor product. The subject of finishing temperatures for hammer forgings seems to have been given but little attention, and the practice in some shops which the writer has observed has been, if anything, malpractice. As in the case of steel-castings manufacture, the production of forgings is not alone dependent upon the nature of the steel. The question of correct finishing temperatures is quite without the scope of this writing, but its importance is recognized. From the standpoint of steel metallurgy, the most common defects in forgings which can be traced to bad steel are segregation and seams. When ingots containing blowholes and occluded oxides and slag are cogged down in a universal mill, and then rolled into billets or not, the occluded substances are elongated in the direction of rolling. Blowholes do not close and weld during either rolling or forging, because the surfaces are oxidized and not clean.

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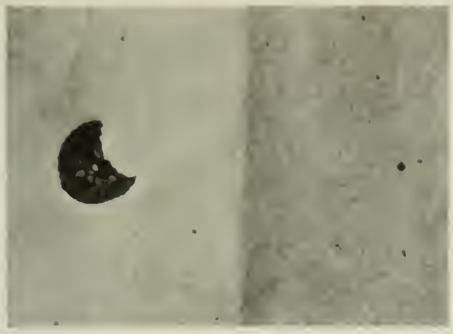
[76] Janssen, W. A., "The Use of Titanium in the Manufacture of Steel Castings," paper read at American Foundrymen's Association meeting, Cleveland, 1916.

[77] Spiegeleisen, of course, could not be employed satisfactorily, as it will add too much carbon to the steel. The question of manganese conservation has been dealt with by the author in another place; see "The Metallurgy of Ferro-manganese," *Iron Trade Review,* March 29, 1917, pp. 723–726; and "Ferromanganese in the Iron and Steel Industry," this JOURNAL, May, 1917, p. 579 *et seq.*

FIG. 17.

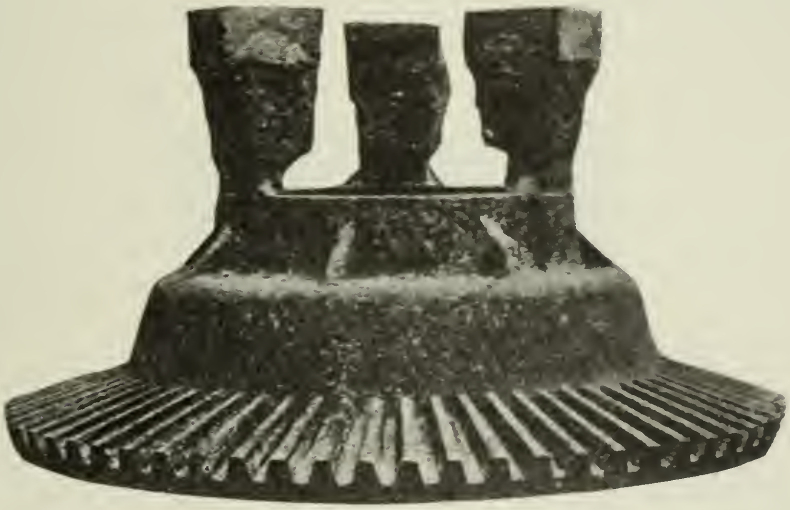


Typical silicate or slag inclusion in plain steel. × 200 diameters. (After Janssen.)

FIG. 18.

Typical small silicate or slag inclusions in titanium treated steel. × 200 diameters. (After Janssen.)

FIG. 19.



Steel crusher gear weighing 5500 pounds, treated with carbon-free ferro-titanium. (After Goldschmidt Thermit Company.)

Forging aggravates these annoyances, as deep-seated ingot occlusions may become surface defects through shaping of the section. Hence it is apparent that the only remedy is the production of a cleaner steel. The employment of the chipping hammer for the removal of seams and cracks in forging billets is a makeshift at best, but where steel makers cannot see the light it is virtually their only salvation. Practical experience shows that the chipping hammer will remove surface defects, but its employment is extremely costly.

Fig. 20.

Streaks of alumina in a billet of forging steel deoxidized with aluminum. Section cut parallel to direction of rolling, not etched. × 200 diameters and reduced one-half. (After Comstock.)

Photomicrographs indicate the value of using titanium for the elimination of occluded oxides and slag from liquid metal before pouring. Figs. 20 and 21 show the comparative values of aluminum and titanium as deoxidizers.

Fig. 21.

Typical small sulphide and silicate fibres in a billet of forging steel treated with titanium. Section cut parallel to direction of rolling, not etched. × 200 diameters and reduced one-half. (After Comstock.)

Titanium in Sheet and Plate Steel.—It is rather doubtful if defects are so noticeable in any other kind of finished steel products, with the possible exception of wire, as in sheets and plates. Sheets for fine automobile-body and fender work, in particular, must be free from surface flaws and defects, and, as elsewhere, the accomplishment of this *desideratum* leads us back to a consideration of the liquid steel. Any ingot defects will certainly be brought to the surface of sheets or plates by the repeated rollings. Steel for plate and sheet-rolling work is made in the usual manner, with the exception of the procedure of adding ferro-phosphorus in the ladle if thin sheets are to be rolled. Other than to the quality of the steel, the causes of defective sheets and plates may be traced to improper rolling and annealing, or to ill-advised pickling practice. These matters are, needless to remark, without the scope of this writing, and no further reference can be made to them here. The question, so far as we are concerned, then lies in the production of good liquid steel, and what has been already said in regard to the use of titanium applies to the production of steel for this purpose.

Titanium in Structural Steels.—Structural shapes, such as channels, angles, tees, I-beams, etc., are rolled in structural-shaping mills, the cast ingots being first cogged down into blooms and then rolled into the various shapes. Most metallurgists have believed that structural steel is rolled, in general, too heavy for the purpose for which it is destined, and differences of opinion have been no uncommon matter between designing engineers and steel makers. Modern office buildings, bridges, and other structures are demanding heavier and still heavier sections. Specifications vary with cities, and there is but little standardization. Disregarding the questions of both design and specifications, there is no question but that segregation is the most serious defect in structural metal. Lives are often dependent on the quality of the steel, and, with this consideration at hand, it seems to be a rather singular thing that the subject has not received more attention. However all that may be, anything which will produce better metal is greatly to be commended, and the results of experimental tests and the usage of practice recommended the titanium alloys for treating the liquid metal before teeming into ingots.

Titanium in Wire Steel.—Steel for wire manufacture is produced in the usual way, ingots being cast in moulds from liquid steel, and the ingots then rolled into billets of small cross-section for drawing. Wire drawing is accomplished by pulling the wire through succeeding smaller dies, the metal being heated so as to be plastic. The small diameter to which the wire is reduced in comparison to the cross-section of the original ingot clearly indicates how internal defects will be brought to the surface. Certain defects of wire, such as a scaly surface due to spongy metal, hard spots due to segregation, and others, are directly traceable to the liquid steel. Other numerous defects are due to wire-drawing practice. Where the steel can be made sound, that should be done. The use of proper deoxidizers, aided by titanium alloys, will eliminate the defects due to the steel to a large extent.

Titanium is an Alloying Element.—Titanium can be obtained in cast iron produced by smelting titanic iron ores, but it is extremely difficult to introduce the element into steel as an alloying constituent.[78] The experiments of W. H. S. Shakell may be instanced to demonstrate the statement just made; a titaniferous sand from New Zealand containing 97.21 per cent. $FeO + Fe_2O_3$, 0.22 MnO, 0.16 Al_2O_3, 0.50 Si, 1.60 per cent. Ti, and CaO, MgO, and alkalies in insignificant amount, was mixed with suitable fluxes and reduced by coke in crucibles. A white pig iron containing 2 to 3 per cent. Ti was secured. The pig iron was reduced with ferro-manganese and a small amount of oxidized metal, giving a steel containing 0.70 per cent. combined carbon, 0.112 Si, 0.623 Mn, 0.098 S, 0.030 per cent. P, and Ti *nil*. This indicates that titanium is much more easily oxidized than silicon.

(*To be continued.*)

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[78] Harbord and Hall, "The Metallurgy of Steel," London, 1911, pp. 402–403.

PHYSICS OF THE AIR.*

BY

W. J. HUMPHREYS,
Professor of Meteorological Physics, United States Weather Bureau.

WINDS DUE TO SIMULTANEOUS ADJACENT LOCAL HEATING AND LOCAL COOLING.

Thunderstorm Winds.

Shortly, say twenty minutes or so, before the rain of a thunderstorm reaches a given locality the wind at that place, generally light, begins to die down to an approximate calm and to change its direction. At first it usually is from the south or southwest in the extra-tropical portion of the northern hemisphere; from the north or northwest in the corresponding portion of the southern, and in both more or less directly across the path of the storm itself. After the change, it blows for a few minutes rather gently, directly toward the nearest portion of the storm front, and finally, as the rain is almost at hand, abruptly and in rather violent gusts away from the storm and in the same direction that it is travelling, a direction that usually differs appreciably from that of the original surface wind. Generally this violent gusty wind lasts through only the earlier portion of the disturbance, and then is gradually but rather quickly succeeded by a comparatively gentle wind, which, though following the storm at first, frequently, after an hour or so, blows in the same general direction as the original surface wind.

The chief cause of these and all other winds peculiar to the thunderstorm, except those within the cumulus cloud itself, is the juxtaposition of warm air immediately in front of the rain and a column or sheet of cold air through which the rain is falling. How this temperature distribution is established and what the results are will be explained later in the chapter on the thunderstorm.

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* Continued from page 551, vol. 184, October, 1917.

CHAPTER VIII.

ATMOSPHERIC CIRCULATION (*continued*).

Winds Due to Widespread Heating and Cooling.

GENERAL REMARKS.

SINCE the atmosphere is a fluid whose viscosity is not only small but also well known, one might suppose, with respect to any given portion, that it would be quite as easy, through the equations of thermodynamics and hydrodynamics, to foretell its every movement and future position as by the equations of celestial mechanics to predict an eclipse or an occultation. But this is far from being the case, and for many reasons. Thus the irregularities of surface heating and surface friction, and the action of mountains, themselves irregular and broken, in deflecting winds, both horizontally and vertically, complicate the problem beyond exact solution. Besides, there are even discontinuities in the amount of atmosphere involved. Water vapor is added in large amounts by evaporation to the volume of circulating gases, mainly in the regions of "highs," while equal average quantities are withdrawn (not simultaneously) by precipitation, chiefly in the regions of "lows." Hence an exact mathematical solution of the problem of world-wide circulation does not seem possible. Nevertheless, many details of this circulation are clearly understood from physical considerations and admit of at least approximate analyses. Some of these details pertain equally to all the more general winds, and therefore a discussion of them will be given independently as a common introduction to the more extended accounts of certain types of atmospheric circulation that follow under the captions monsoons, hurricanes, trade winds, cyclones, etc.

Irregularities, Gusts or Puffs.—Though the wind at an altitude of 200 metres or more is comparatively steady, except in very rough or mountainous regions, near the surface of the earth any appreciable wind that may exist is always in a turmoil, owing to surface friction that checks the lower layer while the layers above tumble forward and down, and to numerous obstructing objects that block its course and introduce cross-currents. Hence its direction constantly changes through many degrees, while the velocity irregularly but persistently fluctuates from one extreme to another. At one instant the actual velocity may be anything up to 50 per cent. or more greater than the average velocity, while a second or two later it may be fully 50 per cent. less than the average. The greater the average velocity the greater, roughly, in the same proportion, the absolute change, as illustrated by Fig. 29. So great, indeed, are these irregularities that places near the surface of the earth not more than 15 metres (50 feet) apart, though having the same average wind direction and velocity, commonly have different, often very different, simultaneous directions and velocities, and therefore, for the instant, radically different winds.

These facts are of great importance with reference to the wracking effect winds have on houses, bridges, and other structures. They also deeply concern the aviator when starting and landing. But, however valuable for many reasons an exact knowledge of surface air movements would be, it is obvious that they defy all formulæ, and that mathematical equations can no more predict the course and speed of a given portion of turbulent surface air than they can mark the path and fix the velocity of water in the swirls and eddies of a mountain torrent. Nevertheless, the average effect of a group of turbulent wind eddies, like the average effect of a large number of gas molecules, does profitably yield to mathematical discussion.[33]

Interzonal Drift.—Although the atmosphere moves mainly from west to east in middle latitudes and from east to west in equatorial regions, it nearly always has a north-south component that produces an interzonal drift. This is simply because the major temperature contrasts of the surface of the earth are between the equatorial and polar regions. Hence, whatever the local or secondary temperature contrasts, of which there are many, and whatever the deflecting barriers and other obstacles that prevent the latitudinal circulation from being free and rapid, it nevertheless must and does obtain to a greater or less extent.

Change of Velocity with Change of Latitude.—The velocity of the earth's surface at and near the equator, as a little calculation shows, is about 1675 kilometres (1040 miles) per hour from west to east, while, with reference to this surface, the velocity of the atmosphere from east to west in the same region is

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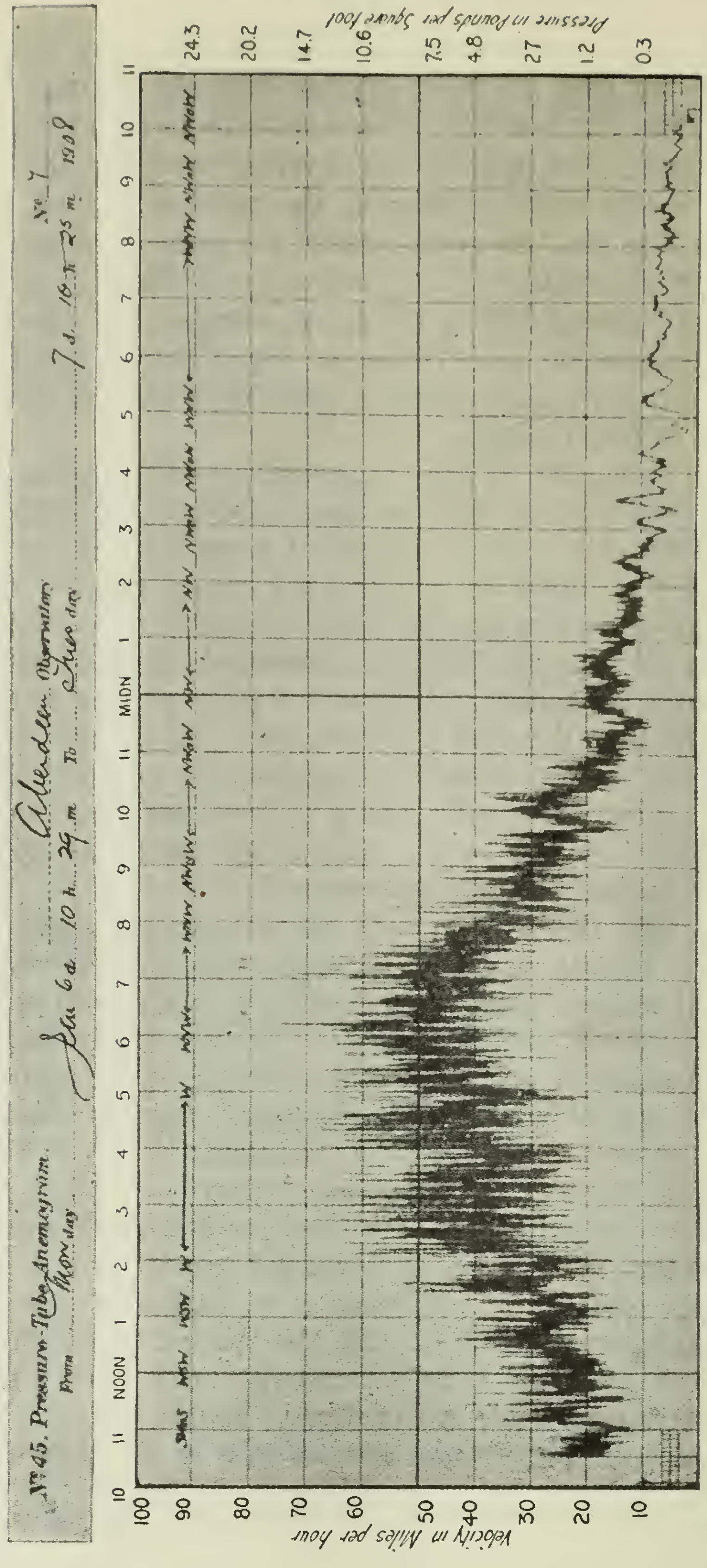
[33] Taylor, *Phil. Trans. Roy. Soc.*, A, 215, pp. 1–26, 1915.

FIG. 29.



Irregularities in the surface wind velocity as indicated by a pressure-tube anemometer.

only a small fraction of this value. In reality, therefore, the atmosphere of equatorial regions is also moving from west to east with a great velocity, though not so great as that of the surface of the earth itself.

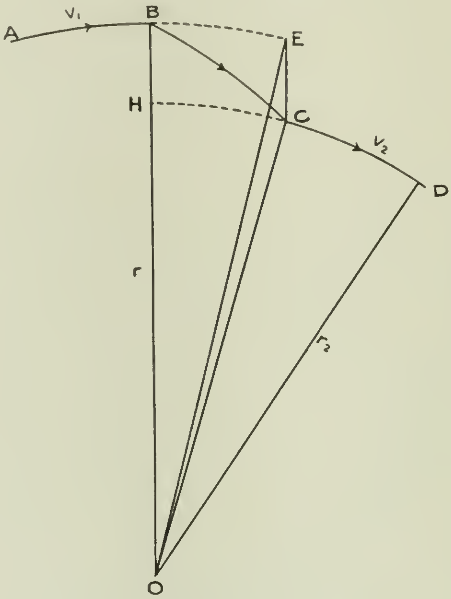
When this air moves to higher latitudes, as it does under the influence of the great temperature contrasts between equatorial and polar regions, it is obvious that its velocity with reference to the surface of the earth must change. It might seem, as many have assumed, that the linear velocity of the air would remain constant, and that the wind would have a west to east component as soon as it had crossed that latitude on which the surface velocity is the same as the original west to east wind movement. This method, however, of considering the problem is theoretically incorrect, as has often been explained. A particle of the atmosphere, or any portion of it moving as a unit, is mainly, at times wholly, rotating around the axis of the earth. In considering latitude effect, therefore, or effect of distance from this axis on wind velocity, it is necessary, as Ferrel first insisted, to remember that the angular momentum $mr^2\omega$ (in which m is the mass, r its distance from the axis of rotation, and ω the west-east angular velocity), and not the linear momentum mv (in which v is the west-east linear velocity), is a constant. In other words, the law of conservation of areas applies. Hence as a given mass of air reaches higher latitudes the absolute value of its east-west component tends, not to remain the same as is often supposed, but actually to become greater in proportion to the secant of the latitude. If the trend of the air is to lower latitudes, its west-east velocity obviously tends to get slower at the same rate that when going to higher latitudes it tends to become faster.

Law of Conservation of Areas.—The law of the conservation of areas as applied to the atmosphere is of sufficient importance to justify its brief demonstration.

Let O, Fig. 30, be the centre about which a mass m is moving with the linear velocity v_1 along the circular arc AB whose radius is r_1. Let m be constrained to follow its path by a central force; that is, a force directed towards O. For instance, let it move over a frictionless horizontal plane, and be kept in its orbit by the tension on a weightless string connecting it with the centre O. At B let the tension on the string be so increased that the mass m will be drawn in the distance BH in the same time that, undisturbed, it would have reached *E*. During this time the path will be something like *BC*. If the tension again becomes constant with the value appropriate to the point *C*, the new orbital velocity will be v_2 along the arc *CD* of radius r_2.

By taking the time interval smaller and smaller the velocity along *BH*, however irregular, approaches uniformity as its limit, while *BE* and *BC* both approach straight lines. With the two component velocities along *BE* and *BH* respectively uniform it is obvious that the resultant velocity along *BC* must also be uniform. The problem of vectorial areas reduces, therefore, to finding the general relation of a radius vector to the normal component thereto of the corresponding orbital velocity. This relation may be shown as follows:

FIG. 30.



Velocities along arcs of different radii.

Let *BC*, Fig. 31, be a rectilinear section of the orbit, usually of infinitesimal length, along which the velocity is uniform, and let *OB* and *OC* be two radii. From *B* draw *BE* perpendicular to *OC* extended, and from *C* draw *CA* perpendicular to *OB*. Hence

$$\frac{AC}{BE}=\frac{v_1}{v_2}$$

in which v_1 and v_2 are the components of the uniform velocity along *BC* at right angles to *OB* and *OC*, respectively. But from the similarity of the triangles OAC and OEB it follows that

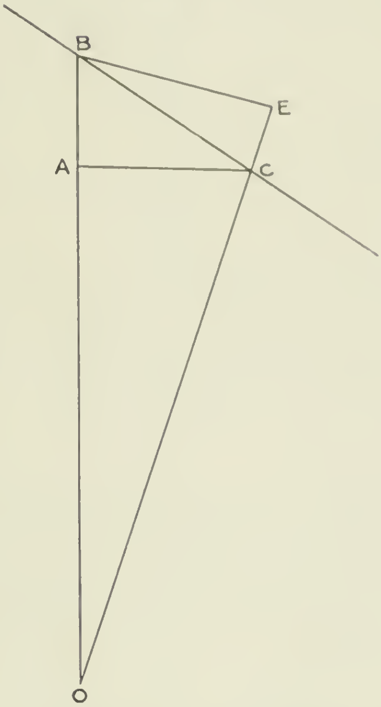
$$\frac{AC}{BE}=\frac{OC}{OB}$$

and, therefore, that

$$\frac{v_1}{v_2}=\frac{OC}{OB}$$

That is, $rv=k$, a constant, in which r is the radius vector and v the component of the orbital velocity at right angles thereto.

FIG. 31.



Conservation of areas in a plane.

But, by elementary geometry,

$$rv=2a,$$

in which a is the rate at which area is covered by the movement of r. Hence whatever the portion of the orbit, the radius vector sweeps over equal areas in equal intervals of time, or whatever the points selected,

$$\frac{v_1}{v_2}=\frac{r_2}{r_1}$$

The kinetic energy E_1 of the mass m while on the arc AB, Fig. 30, is given by the equation,

$$E_1=\tfrac{1}{2}mv_1^2.$$

Similarly, its kinetic energy along CD is given by

$$E_2 = \tfrac{1}{2} m v_2^2.$$

These are unequal, the difference being

$$\frac{m}{2}(v_2^2 - v_1^2),$$

and it will be interesting to find the source of inequality.

At all parts of the orbit the tension f on the string is given by the equation,

$$f = \frac{mv^2}{r}$$

and the work, dw, done on shortening the radius by the small amount dr is expressed by the equation,

$$dw = -\frac{mv^2}{r} dr.$$

But since $rv = k$, $v = \frac{k}{r}$, and

$$dw = -\frac{m\,k^2}{r^3} dr.$$

Hence on shortening the string from r_1 to r_2 the work becomes,

$$W = m\,k^2 \int_{r_2}^{r_1} \frac{dr}{r^3} = \frac{m}{2}\left(\frac{k^2}{r_2^{\,2}} - \frac{k^2}{r_1^{\,2}}\right).$$

But $k^2 = v^2 r^2 = v_1^{\,2}\,r_1^{\,2} = v_2^{\,2} r_2^{\,2} =$ etc.

Hence $W = \frac{m}{2}(v_2^2 - v_1^2)$.

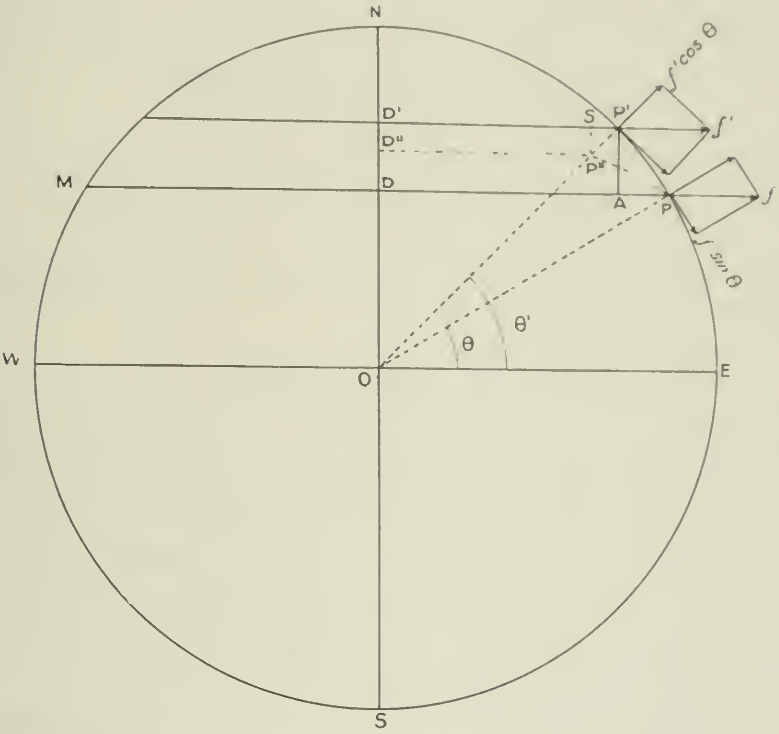
But this is identical with the value already found for the difference between the kinetic energies of m at the distances r_1 and r_2 from O. That is, this difference is equal and due to the work done on m by the tension on the string while decreasing the radius from r_1 to r_2.

Consider now the velocity of a quantity of air or other mass moving as a unit frictionlessly over the surface of the earth. Let the mass m, regarded as a point (in the case of an extended body it is $\Sigma\, mvr$ that remains constant), be at P, Fig. 32, rotating around the axis NS on the small circle MP and held to the surface by gravity directed towards the centre O. If v is the linear velocity of m, it follows that the radially directed force f is expressed by the equation,

$$f = \frac{mv^2}{r} = \frac{mv^2}{DP}.$$

On forcing this mass to a higher latitude, to P', say, work is done against the horizontal component of f. But from the similarity of triangles it is obvious that at every point along the arc PP', $f \sin \theta$, the force to overcome, is to f, the centrifugal force, as the rate of approach to the axis is to the rate of progress along the meridian. Thus the work done in going from P to P' is the same as that which would be done in shortening the radius DP to DA. But, as above explained, this work on m, or transfer of energy to it, must appear as so much additional kinetic energy, friction being excluded. Hence the orbital velocity v' at P' is to the orbital velocity v at P as DP is to $D'P'$. That is,

FIG. 32.



Conservation of areas on a sphere.

the conservation of areas holds likewise in this case, where the radius vector is the normal from the moving mass to the axis of rotation.

This same law holds also on the slightly flattened earth. To make this clear, let PP'' be a portion of a greatly flattened meridian, and let the mass m be taken from P to P' as before, and thence to P''. From P' to P'' the work is against the force $f' \cos \theta'$, and obviously equal to the work against f' over the distance $P'S$. Hence the orbital velocity of m at P'' is to its orbital velocity at P as DP is to $D''P''$.

Suppose a quantity of quiet air, air moving strictly with the surface of the earth, at, say, latitude 30 degrees, is forced to higher latitudes, as it actually is by pressure gradients due to temperature differences, what, according to the law of the conservation of areas, will be its final surface velocity at, say, latitude 60 degrees?

At latitude 30 degrees its orbital velocity, being the same as that of the surface, is, approximately,

$$v = \frac{2\pi 3957 \cos 30^\circ}{24} = 897.2\,\frac{\text{miles}}{\text{hour}} = 401.1\,\frac{\text{metres}}{\text{second}}.$$

At latitude 60 degrees its orbital velocity is, from the principle stated,

$$v' = v\,\frac{\cos 30^\circ}{\cos 60^\circ} = 1554\,\frac{\text{miles}}{\text{hour}} = 694.7\,\frac{\text{metres}}{\text{second}},$$

while at latitude 60 degrees the orbital velocity of the surface is

$$s = \frac{2\pi 3957 \cos 60^\circ}{24} = 518\,\frac{\text{miles}}{\text{hour}} = 231.6\,\frac{\text{metres}}{\text{second}}.$$

Hence the velocity of the transferred air in question with reference to the surface is

$$v' - s = 1036\,\frac{\text{miles}}{\text{hour}} = 463.1\,\frac{\text{metres}}{\text{second}}.$$

As a matter of fact, no such enormous velocities of the wind as the principle of the conservation of areas would lead one to expect in the higher latitudes are ever found, either at the surface or at other levels. This, however, does not argue against the applicability of the principle itself, but only shows that in the case of atmospheric circulation there are very effective damping or retarding influences in operation.

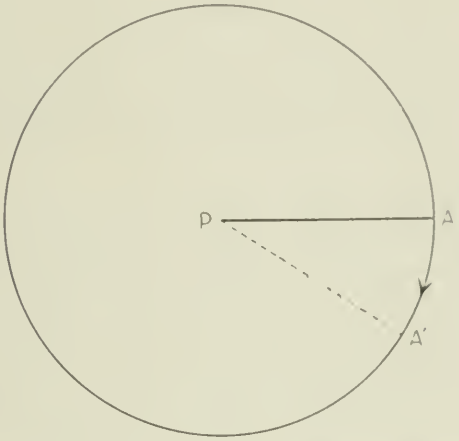
The resistance due to the viscosity of the atmosphere is one of these retarding influences, but its effect probably is very small. A larger effect doubtless comes from surface turbulence induced by trees, hills, and other irregularities. A still greater velocity control, probably so great that all others are nearly negligible in comparison, except near the surface, is vertical convection. This phenomenon leads to extensive interchange between lower and upper layers of the atmosphere, thus indirectly increasing the effect of surface friction probably several fold and tending to bring all the lower, vigorously convective, portion of the atmosphere to a common velocity. Because of these several means of control the actual wind velocity everywhere is different, and at high latitudes much less than it otherwise would be.

Not only is the velocity of the wind changed through change of latitude, but also the rate at which its direction with reference to the surface of the earth varies or tends to vary, as will appear from what follows.

Deflection Due to the Earth's Rotation.—The effects of the rotation of the earth on the direction of the wind are of extreme importance to the science of meteorology. It will be convenient, therefore, before going further, to consider how these important results are produced and to form some idea of their approximate magnitudes.

An exact discussion of this problem is somewhat tedious, but a very approximate solution is readily obtained. To this end, let P, Fig. 33, be one pole of the earth—the north pole, say—assume the surface to be flat, which it very approximately is, at and near this point, and let a particle of air cross it in the direction PA with the uniform velocity v; let the earth rotate in the direction AA' with the angular velocity ω, and let the distance which the air particle under consideration has gone from P in the brief time dt be such that

FIG. 33



Deflection, at pole, due to the earth's rotation.

$$PA = dr = vdt.$$

Let the meridian along which the particle started as it left P have the position PA' at the end of the time dt, or when the particle, keeping a constant direction in space, has arrived at A. Obviously the velocity with which the earth moves under the particle increases directly with the distance from P. But as this latter is directly proportional to the time dt since the particle left

P, v being a constant, it is clear that the distance, travelled normally to the instantaneous meridian, ds, say, may be expressed in terms of a constant acceleration, a, in the direction opposite to that of rotation. That is,

$$ds = \tfrac{1}{2} a(dt)^2.$$

Also

$$ds = dr\ \omega\ dt = v\ dt\ \omega\ dt = v\ \omega\ (dt)^2.$$

Hence,

$$\tfrac{1}{2}\ a\ (dt)^2 = v\ \omega\ (dt)^2,$$

or

$$a = \omega\ v.$$

Since a force is measured in terms of mass times acceleration, it follows that the west-east deflective force, f, that would keep a mass m, of atmosphere or anything else, next the pole in the same meridian, or the east-west force that, if the earth were still, would produce the given motion with reference to its surface, is very approximately given by the equation,

$$f = ma = 2\ m\ \omega\ v,$$

where v and ω have the values above assigned.

Let the moving particle under consideration be not at one of the poles, but at some other point, such as P, Fig. 34, at latitude ϕ. Resolve the angular velocity ω, about ON, into its components about the right-angled axes OP and OP'. These components, as is well known, are $\omega \sin \phi$ about OP and $\omega \cos \phi$ about OP'.

Now all points on and exceedingly close to the equator of a rotating sphere have sensibly the same velocity, hence the direction and velocity of horizontally moving particles at P are affected by the component of rotation about OP only, and not at all by the component about OP'.

That is, at N, as already explained,

$$a = 2\ \omega\ v, \text{ and } f = 2\ m\ \omega\ v,$$

while at latitude ϕ, where the angular rotation is $\omega \sin \phi$,

$$a = 2\ \omega\ v \sin \phi, \text{ and } f = 2\ m\omega v \sin \phi,$$

to the right (going forward with the particle) in the northern hemisphere, to the left in the southern.

From this simple equation, assuming it to be exact, which it very nearly is, it follows that the deflective force due to the rotation of the earth acting on a quantity of moving air (that is, the force that, assuming the earth to be still, measures the existing tendency of wind to change its direction with reference to any fixed line on the adjacent surface) is:

a. Directly proportional to its mass.

b. Directly proportional to its horizontal velocity.

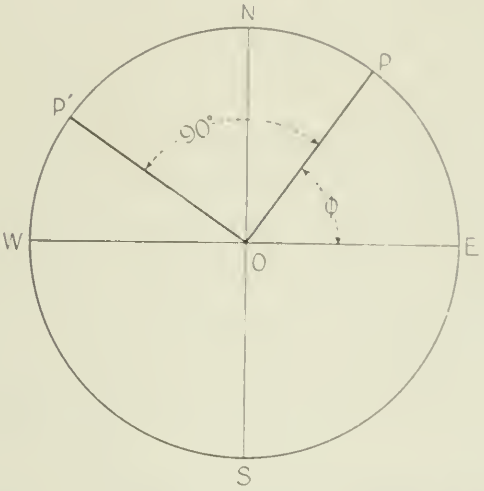
c. Directly proportional to the angular velocity of the earth's rotation.

d. Directly proportional to the sine of the latitude of its location.

e. Exactly the same whatever its horizontal direction.

f. Always at right angles to its instantaneous direction and therefore wholly without influence on the velocity with reference to the surface.

FIG. 34.



Deflection, away from pole, due to earth's rotation.

g. Opposite to the direction of the earth's rotation. Hence to the right, or clockwise in the northern hemisphere; to the left, or counter-clockwise in the southern.

Since the deflection acceleration is all the time at right angles to the path, it follows that an object moving freely over the surface of the earth would describe an endless series of curves. At each point on this path the acceleration at right angles to it, measured with reference to the surface of the earth, is given, as explained, by the equation,

$$a = 2\,\omega\, v \sin\phi,$$

in which the terms have the values assigned above. It is also given by the well-known equation for acceleration along a radius of curvature. That is,

$$a=\frac{v^2}{r},$$

in which, since the force is tangent to the earth, $r=R\tan\alpha$, where R is the radius of the earth, and α the angle subtended at the centre of the earth by the radius of the path at the point under consideration. Hence, when the only deflective influence is that due to the earth's rotation,

$$r=\frac{v}{2\omega\sin\phi}, \text{ and } \tan\alpha=\frac{v}{2R\omega\sin\phi}.$$

That is, the greater the linear velocity of the moving object over the surface of the earth, and the nearer it is to the equator, the greater the radius of curvature. On the equator the radius of curvature is infinite, or the path a straight line. However, unless the object is moving along the equator it soon gets to one side where the direction of curvature changes, as is well shown by the summer windtracks over the Indian Ocean.

Rate of Change of Wind Direction.—The theoretical rate of change of wind direction at any point on the surface of the earth obviously is the angular velocity ω' of the earth about an axis passing through its centre and the point in question. This change of direction, therefore, clockwise in the northern hemisphere, counter-clockwise in the southern, occurs at a rate *wholly independent* of wind velocity, and is given by the equation,

$$\omega'=\omega\sin\phi,$$

in which ϕ is the latitude of the place under consideration and ω the angular velocity about the axis through the north and south poles.

But, as the earth turns completely around during a sidereal day,

$$\omega=\frac{2\pi}{86{,}164}\text{ per second }=15^\circ\ 2'\ 26''\text{ per hour, or }15^\circ\text{ per hour, roughly. Hence,}$$

$$\omega'=15^\circ\sin\phi\text{ per hour, roughly.}$$

The approximate values of ω' corresponding to different latitudes may conveniently be tabulated as follows:

Earth Rotation in Degrees per Hour of Different Latitudes.

φ	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°
ω	0.00°	1.31°	2.60°	3.88°	5.13°	6.34°	7.50°	8.60°	9.61°	10.61°
φ	50°	55°	60°	65°	70°	75°	80°	85°	90°	
ω'	11.49°	12.29°	12.99°	13.59°	14.10°	14.49°	14.77°	14.94°	15.00°	

It must be clearly understood that the above values of rate of change of direction are based on the assumption that there is no friction and no disturbing horizontal pressure gradient, neither of which is true with reference to actual winds. Nevertheless, the values obtained are important, since they indicate the natural torque of the atmosphere, or its tendency to rotate when set in motion by pressure gradients.

It is interesting and quite practicable, as Whipple[34] has shown, to compute the path of a frictionless mass over the rotating earth when its direction and velocity are given for any definite point, but this will be omitted, since in the case of the actual atmosphere, because of viscosity, turbulence, surface obstacles, horizontal pressure gradients, etc., the departures from theoretical values are so great that it seems hardly necessary or even safe to go beyond the above simple and general relations.

Centrifugal Deflecting Force of Winds.—Usually the paths of winds are more or less curved, and therefore the moving air exhibits a "centrifugal force," or inertia force away from the centre of curvature in opposition to any applied "centripetal force." The value of this force, f, in the plane of the curve, not the plane of the horizon, is given by the equation,

$$f = \frac{mv^2}{r},$$

in which m is the mass concerned, v its linear velocity, and r the radius of curvature of the path at the place and time under consideration, or radius of the "small circle" in which the air is then moving.

Relative Values of Centrifugal and Rotational Components.—The ratio between the two deflective forces, rational and centrifugal (centrifugal action of the earth's rotation and centrifugal action due to curvature of path), varies greatly with the velocity of the wind, radius of curvature of its path, and latitude of its location. Within 20 degrees, at least, of the equator cyclonic storm winds commonly move on curves whose radii are comparatively small, 150 kilometres (93.2 miles) or less, in which case the centrifugal deflective force generally is greater than the rotational. In middle and higher latitudes, however, the average radii of cyclonic wind-paths usually are much larger, say 600 kilometres (373 miles), and the rotational deflective force greater than the centrifugal.

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[34] *Phil. Mag.*, 33, p. 457, 1917.

A few numerical examples will be interesting. No effort has been made to get average values, but only such as presumably often occur.

Ratios of Deflective Forces Under Given Conditions.

Latitude	Radius of curvature	Gradient velocity	$\frac{\text{Rotational force}}{\text{Centrifugal force}}$
	Miles	Miles per hour	
10°	20	80	1/44
20°	30	70	1/13
30°	100	50	10/19
40°	400	40	10/3
50°	400	35	14/3
60°	400	35	26/5

In tropical cyclones, therefore, the pressure gradient is balanced mainly by the centrifugal force, while in those of middle latitudes it is balanced chiefly by the rotational deflective force.

Ordinarily, except in the neighborhood of a well-marked low, the radius of curvature is much larger than any of the values above assumed, and consequently the ratio of rotation to centrifugal force correspondingly greater.

Total Horizontal Deflecting Force.—If the path of the air is at all curved, as it usually is, the total *horizontal* deflecting force, *F*, due to its velocity is given by the equation,

$$F = 2\, m\, \omega\, v \sin \phi \pm \frac{mv^2}{r},$$

in which $r = r' \sec\alpha$, r' and α being the linear and angular radii (as seen from the centre of the earth) respectively of the "small circle" in which the air is moving, or $r = R \tan \alpha$, R being the radius of the earth, and the other symbols have the meanings given above. The positive sign is used, or the deflective forces are additive, in the northern hemisphere when the course of the wind is counter-clockwise; in the southern hemisphere when the course is clockwise. The negative sign is used in each case when the sense of rotation is reversed. In cyclones, therefore, the total deflecting force is equal to the sum of the centrifugal and rotational deflective forces; in anticyclones to their difference.

When the winds become approximately steady the deflective force obviously is balanced against the gravitational pressure gradient. In symbols,

$$\frac{1}{\rho}\frac{dp}{dn} = 2\,\omega\,v \sin\phi \pm \frac{v^2}{r},$$

in which ρ is the density of the air, dp the slight difference between the pressures at the ends of the short horizontal distance dn at right angles to the path at the place considered. The meanings of the other symbols are given above. If the gradient is zero (that is, if the air moves without lateral restraint), $r = \frac{v}{2\omega \sin\phi}$, as previously shown, or $R \tan \alpha = \frac{v}{2\omega \sin\varphi}$; also, from the equation just given, $2\,\omega\ v \sin \phi \pm \frac{v^2}{r} = 0$. Hence, under the assumed conditions, $r = R \tan \alpha = \infty$; that is, $\alpha = 90°$, or the path is a great circle. However, these latter equations have but little more than a theoretical interest, since without the driving force of a pressure gradient wind velocity can neither be acquired nor (because of friction) maintained.

GRADIENT WIND.

Gradient Velocity.—That velocity of the air at which the deflective force due to the rotation of the earth and the centrifugal force jointly balance the horizontal pressure gradient is called the gradient velocity. It does not occur near the surface of the earth, owing to surface friction, but "from kite observations, it appears that at 1500 feet above the surface the agreement [between the observed and 'gradient' velocities] is generally very close,"[35] especially in the absence of thunderstorms and other local disturbances. This does not mean that the wind has the same velocity at all levels beyond ½ kilometre, but only that above this height the velocity of an approximately steady wind is very nearly the gradient velocity appropriate to the atmospheric density, horizontal pressure gradient, and latitude at the place in question.

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[35] Shaw, "Forecasting the Weather," p. 45.

If the sense of rotation is that which exists in a cyclone, the two deflective forces are additive, as stated above, and the gradient velocity is given by the general equation,

$$v = \pm\sqrt{\frac{r}{\rho}\frac{dp}{dn} + (r\,\omega \sin\phi)^2} - r\,\omega\sin\phi, \quad . \quad . \quad . \quad . \quad . \quad (A)$$

in which the sign of the radical remains to be determined.

But obviously $v = 0$ when $\frac{dp}{dn} = 0$, as there can be no wind without a pressure gradient, from which it follows that the sign of the radical is positive, and that actually

$$v = \sqrt{\frac{r}{\rho}\frac{dp}{dn} + (r\,\omega\sin\phi)^2} - r\,\omega\sin\phi \quad . \quad . \quad . \quad . \quad . \quad . \quad (B)$$

Theoretically this wind at any place is *along* the corresponding isobar, parallel, roughly, through the first one or two kilometres of elevation, to the surface isobar, and always in such direction that one moving with it will have the *lower* pressure to his *left*. It must be distinctly noted, however, that the above equations presuppose absence of friction and the attainment of a steady state. They therefore give the approximate wind velocity and direction only for levels above the appreciable reach of surface turbulence, and even there in the cases only of smooth and regular isobars. Near the surface where the velocity is checked by friction the wind direction is correspondingly deflected toward the region of lower pressure.

In the C. G. S. system of units:

v = centimetres per second.

$\frac{dp}{dn}$ = difference in dynes pressure per square centimetre, per centimetre horizontal distance at right angles to isobars. $r = r' \sec \alpha$; r' = radius of curvature, in centimetres, of wind-path at time and place of observation, *not distance to the centre of the low;* α = angular radius, measured from the centre of the earth, of the "small circle" along which the wind is moving. Ordinarily r differs from r' by less than 1 part per 100, and therefore, in practice, they may be assumed to have equal values.

ρ = grammes of air per cubic centimetre.

ω = angle through which the earth turns per second, $\frac{2\pi}{86,164}$

$\sin\phi$ = natural sine of the angle of latitude.

If the path of the wind is straight (that is, if there is no centrifugal force), the equation for gradient velocity is

$$v = \frac{\frac{dp}{dn}}{2\omega\rho\sin\phi}.$$

In anticyclonic regions gradient winds, as explained, obey the equation,

$$\frac{1}{\rho}\frac{dp}{dn} = 2\omega v\sin\phi - \frac{v^2}{r},$$

or,

$$v = r\omega\sin\phi \pm \sqrt{(r\omega\sin\phi)^2 - \frac{r}{\rho}\frac{dp}{dn}} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (C)$$

As above,

$$v = 0 \text{ when } \frac{dp}{dn} = 0.$$

Hence, in this case, the sign of the radical is negative and

$$v = r\omega\sin\phi - \sqrt{(r\omega\sin\phi)^2 - \frac{r\,dp}{\rho\,dn}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (D)$$

Obviously, then, as pointed out by Gold,[36] steady anticyclonic winds cannot become intense, since the maximum possible velocity is given by the equation,

$$v \text{ max} = r\omega\sin\phi.$$

For example, if $r = 500$ kilometres, and $\phi = 40°$,

v max = 23.4 metres per second = 52.3 miles per hour.

The gradient that produces this velocity is given by the equation,

$$\frac{dp}{dn} = \rho\, r\,(\omega\sin\phi)^2.$$

On substituting this gradient in the equation above for straight winds, it appears that it would give the velocity,

$$v = \frac{\rho\, r\,(\omega\sin\phi)^2}{2\,\rho\omega\sin\phi} = \tfrac{1}{2}\, r\,\omega\sin\phi.$$

That is, the limiting velocity of anticyclonic winds,

$$v \text{ max} = r\,\omega\sin\phi,$$

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[36] M. O., No. 190, "Barometric Gradient and Wind Force," London, 1908.

is just twice that which the corresponding pressure gradient would give to straight winds.

Since " for the time being, we may regard the gradient winds as the best estimate we can give of the actual winds at, say, 1500 feet above the surface," [37] it seemed advisable to construct tables (see Appendix), one for cyclonic, the other for anticyclonic conditions, that give the theoretical wind velocities in metres per second, kilometres per hour, and miles per hour for various latitudes, radii of curvature, and pressure gradients, as indicated, each to be used in conjunction, of course, with the current weather map, corrected, if need be, by estimation or by special reports, for the hours that have elapsed since the observations were made from which it was constructed.

As the equations demand and the tables indicate, the winds of an anticyclone, gradient for gradient, latitude for latitude, and curvature for curvature, are stronger, often much stronger, than those of a cyclone. This may seem to be flatly contradicted by the fact that anticyclones are characterized by relatively light winds, but the contradiction is only apparent, for, as the equations show, steep gradients cannot obtain in anticyclonic regions, nor, therefore, heavy winds except near their borders, or when r is large. However, in general, strong anticyclonic winds cover only a narrow strip of territory, and their duration, therefore, is comparatively brief.

Figs. 35, 36, and 37 represent respectively the effect of latitude, pressure gradient, and radius of curvature on the " gradient " velocity, other things in each case being constant.

Surface gradients and surface isobars, when well defined and in the absence of local disturbances, may be used for approximate values up to elevations of, roughly, two kilometres, except wherever the horizontal temperature gradient is steep and opposite in direction to the horizontal pressure gradient. In such cases the temperature tends to weaken and finally reverse the pressure gradient with increase of elevation. Hence, since the temperature gradient is nearly always more or less poleward, in extra-tropical regions the east wind generally is the shallowest and the least likely to have, at an elevation of two kilometres, say, the direction and velocity computed from the surface system of isobars; and the west wind the deepest, with direction and velocity closest in agreement with the values thus computed. In short, with increase of elevation the isobars, usually closed on the surface, tend to

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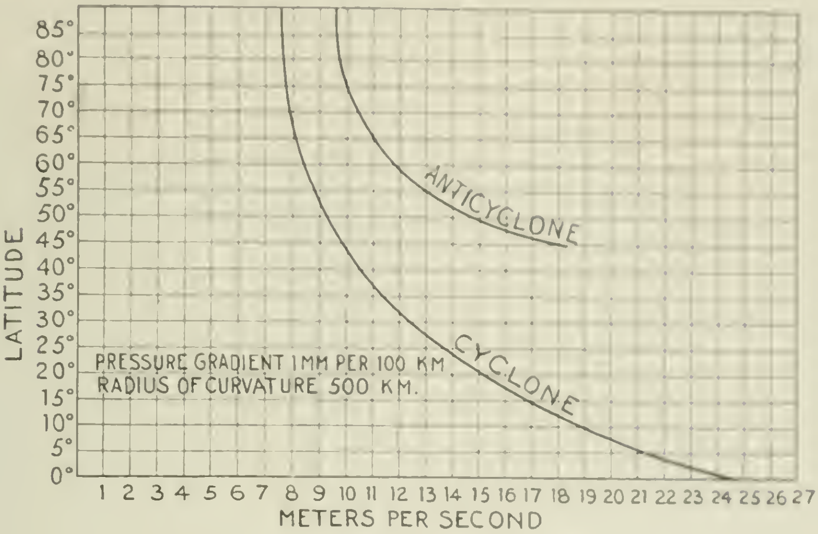
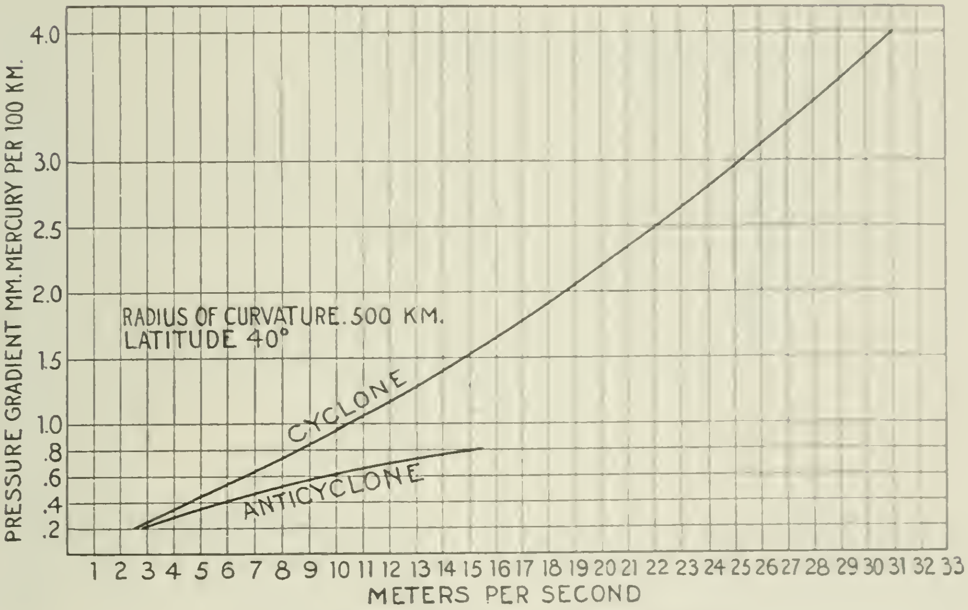
[37] Shaw, " Forecasting the Weather," p. 49.

FIG. 35.



Relation of gradient velocity to latitude.

FIG. 36.



Relation of gradient velocity to pressure gradient.

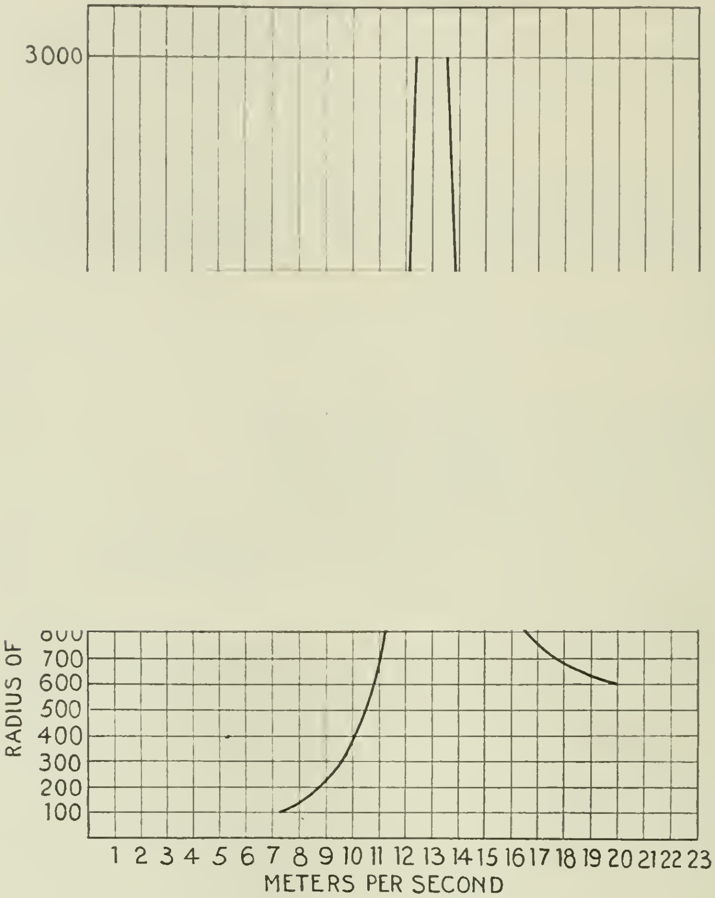
open out and roughly to follow the parallels of latitude with the decrease of pressure, at least to well above the troposphere, directed poleward.

Gradient Velocity Nomogram.—The general gradient velocity equation, $F = 2m\omega v \sin\phi \pm \frac{mv^2}{r}$, reduces, on dividing by m, to

$$2\omega v \sin\phi - \frac{1}{\rho}\frac{dp}{dn} = \pm\frac{v^2}{r},$$

the upper sign being used for anticyclones and the lower for cyclones.

FIG. 37.



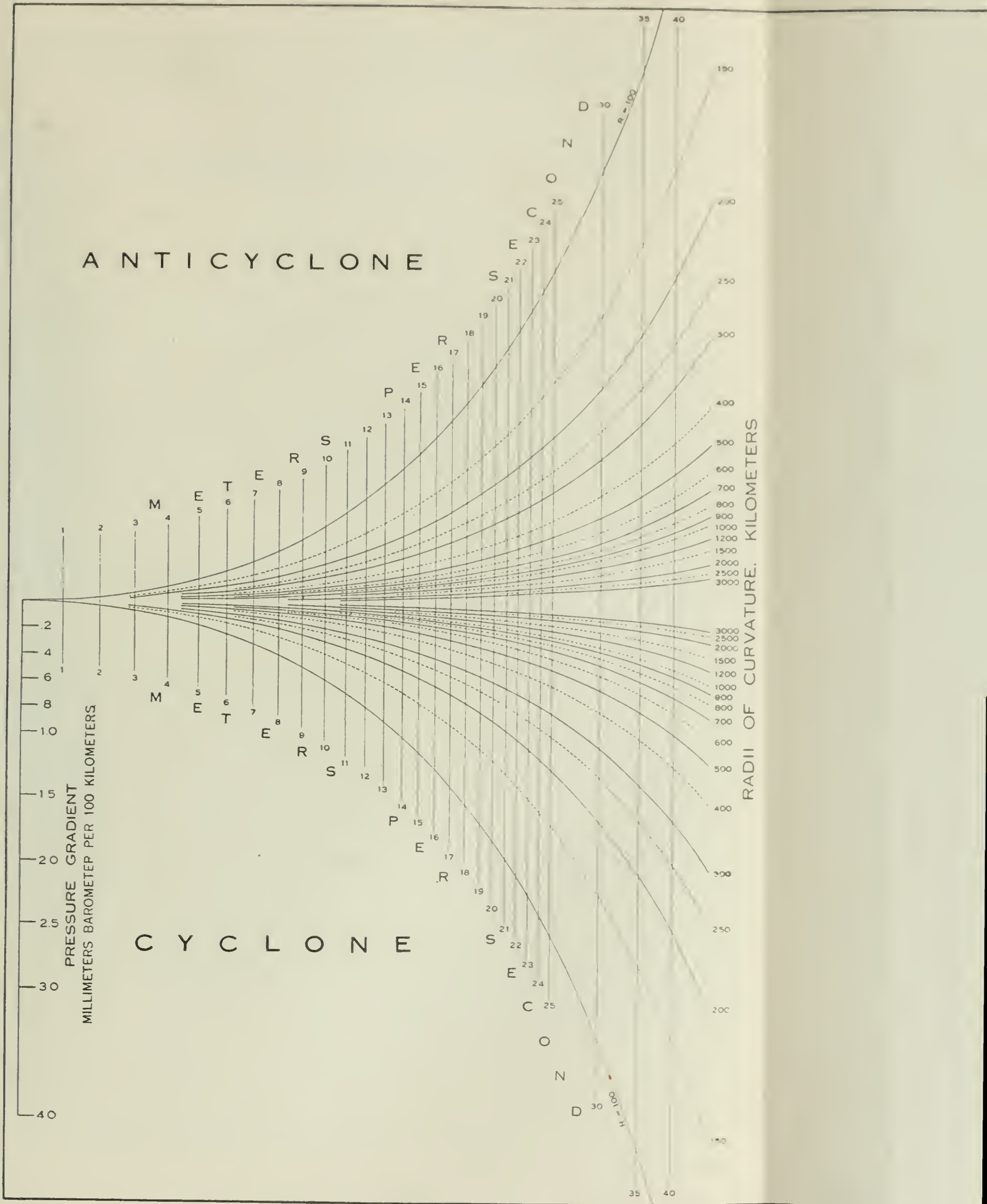
Relation of gradient velocity to radius of curvature.

A straight line nomogram that solves this equation has been constructed by Mr. Herbert Bell, of the University of Michigan, after the method developed by Professor d'Ocagne in his "Traité de Nomographie." The solution is as follows:

Writing

$$u = -\frac{20}{\rho}\frac{dp}{dn}, \text{ and } w = 10^5\omega\sin\phi,$$

Fig. 38.



Gradient velocity nomogram.

u and w being scales along the lines $x = -10$ and $x = 10$ respectively, the velocity equation becomes

$$2500\,u + v\,w = \pm\,50{,}000\,\frac{v^2}{r}$$

which is linear in u and w.

If, then, a network is constructed of the two families

$$x = 10\,\frac{v - 2500}{v + 2500} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

and

$$y = \pm\,\frac{50{,}000\,\dfrac{v^2}{r}}{v + 2500}$$

$$= \pm\,\frac{6.25 \times 10^6}{r}\,\frac{(10 + x)^2}{10 - x} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

the point c, say, determined by (1) and (2) from values of v and r, will be collinear with the point A on the u scale, fixed by the given value of $\frac{dp}{dn}$, and the point B on the w scale indicated by the latitude.

The resulting diagram, with gradients in terms of millimetres difference of barometer reading per 100 kilometres, and velocity in metres per second, is given in Fig. 38.

To find the gradient wind velocity, connect the known pressure gradient (marked on lower left border of the diagram) and the latitude of the place in question (given on the upper right border) with a straight edge or stretched string and note where it cuts the curve representing the radius of curvature of the local isobar. For *cyclones* the vertical through this point gives the required velocity in metres per second. For *anticyclones* two velocities are thus indicated, but the *smaller* is the one to take, since it alone is physically possible. See equations C and D, above.

This nomogram should be used in conjunction with the surface distribution of pressure only in the absence of local disturbances (thunderstorms, squalls, etc.); where the pressure gradient is well defined—isobars smooth and regular, and for elevations between, roughly, 500 and 2000 metres.

(*To be continued.*)

EXPERIMENTAL TEST OF THE WIEDEMANN-FRANZ RATIO THROUGH A CHANGE OF STATE.*

BY

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AND

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THE best conductors of electricity are, in general, the best conductors of heat. The ratio of the thermal to the electrical conductivity for all pure metals at the same temperature has nearly the same value when the temperature is in the neighborhood of 20° C. The value of this ratio is assumed to be proportional to the absolute temperature.

If we call k thermal conductivity, σ the electrical conductivity, α the universal gas-constant, e the electrical charge carried by a univalent electrolytic ion, and T the absolute temperature, then the law, which has long been known as the result of observations and generally called the Wiedemann-Franz law, states that

$$\frac{k}{\sigma} = \frac{4}{3}\left(\frac{a}{e}\right)^2 T = 0.715 \times 10^{-10} \text{ at } 18^\circ \text{ C}.^{[1]}$$

This law holds remarkably well for pure metals, less accurately for alloys, and not at all for poor conductors. How well it holds for the pure metals is exhibited in the table on page 68 of Campbell (see reference below). In this table the observed value given for silver is 0.76×10^{-10} and for bismuth 1.068×10^{-10} both at 18° C. Considering the large discrepancy in the resistance values for silver and bismuth, the closeness between these numerical values is very good, and the agreement between both values and the value obtained above for the ratio, obtained upon the basis of pure theory, is quite surprising.

The writers believe that any law which is based upon purely theoretical considerations can only be expected to hold over a comparatively limited range of variation of the magnitudes mutually related by the law. If the law can be shown experimentally to continue to hold when some one of the magnitudes, as the temperature, is varied through a wide range, then its usefulness and universality are both extended.

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* Communicated by Dr. Northrup.

[1] Consult Campbell, "Modern Electrical Theory," 1913 ed., pp. 66–68.

The object of the present investigation was to determine experimentally if the Wiedemann-Franz ratio continues to hold approximately true for two typical metals which change in resistance in opposite directions when these are carried from the solid into the molten condition. The two metals chosen for study were tin and bismuth, because both of these metals have low melting-points and both have been very carefully investigated by the first-named writer in respect to their resistivity characteristics.[2] Thus, the ratio of the electrical resistivity just after fusion (47.4 microhms) to its resistivity just before fusion (22.0 microhms) is 2.154 for the metal tin. Similar figures for the metal bismuth are 267 microhms just before fusion and 127.5 microhms just after fusion, the ratio of the latter to the former being 0.477. For the Wiedemann-Franz ratio to hold for these two metals, when carried from the solid into the molten state, their thermal resistivities or thermal conductivities must likewise change in an abrupt manner and in an opposite direction for each of the two metals.

The investigation which we proceed to describe is not a first attempt to obtain information on this matter. After the present investigation was started an article was found in *The Physical Society of London Proceedings,* vol xxvii, part iv, June 15, 1915, p. 307, on "The Change in Thermal Conductivity of Metals on Fusion," by Alfred W. Porter, D.Sc., F.R.S., and F. Simeon, B.Sc., research scholar University College of London. Sodium and mercury were examined by these writers, using a method radically different from the one employed by us. Metals were placed in a glass tube, the portion in the upper half of the tube being maintained molten and the portion in the lower half of the tube being maintained solid. The ratio required was obtained by comparing the slopes of the tangents to the temperature gradient curves for the molten and the solid portions of each metal.

The results obtained seemed to indicate quite conclusively that the Wiedemann-Franz ratio holds over a change of state

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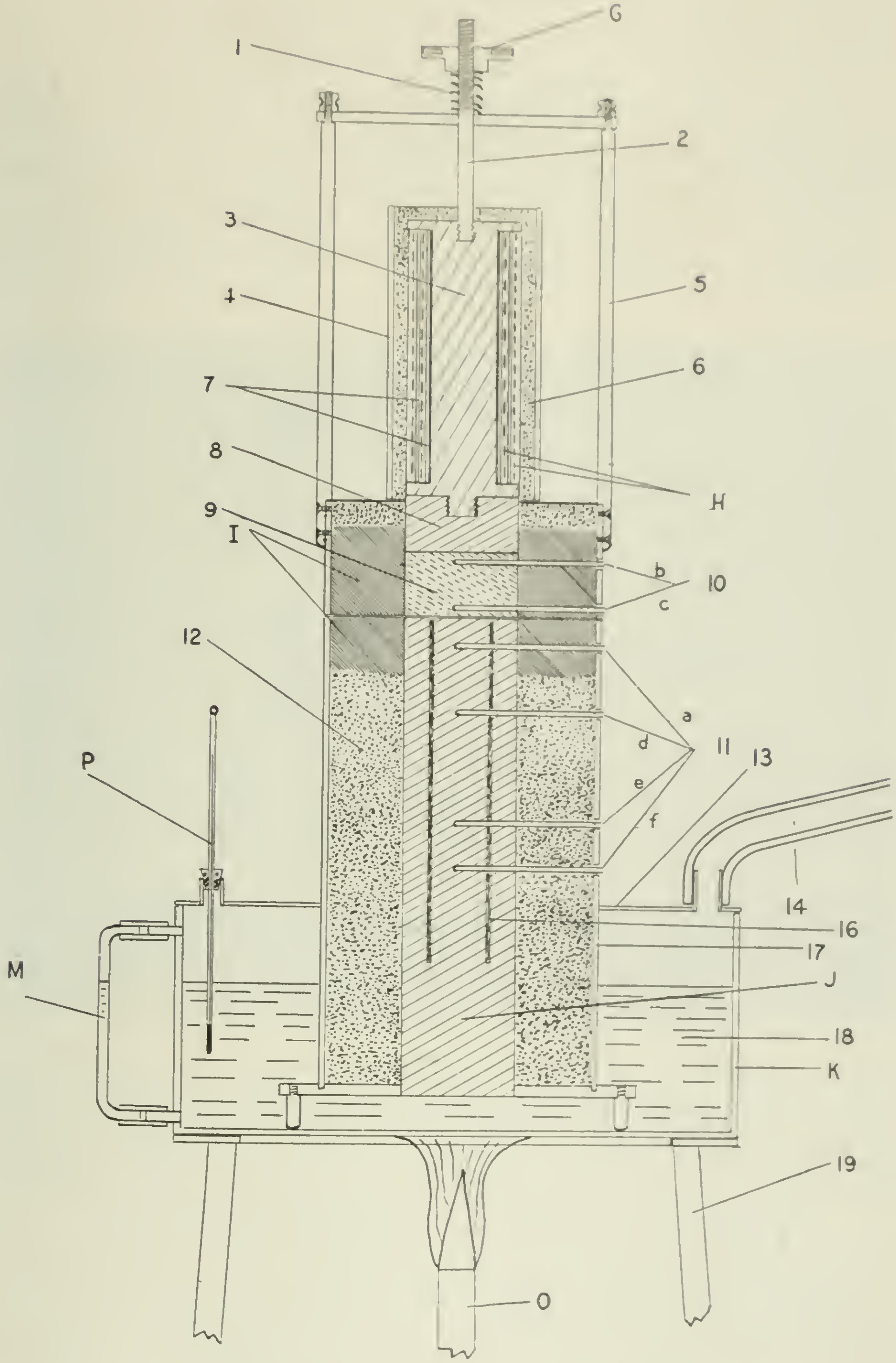
[2] "Resistivity of a Few Metals Through a Wide Range of Temperature," by Edwin F. Northrup and V. A. Suydam, JOURNAL OF THE FRANKLIN INSTITUTE, February, 1913.

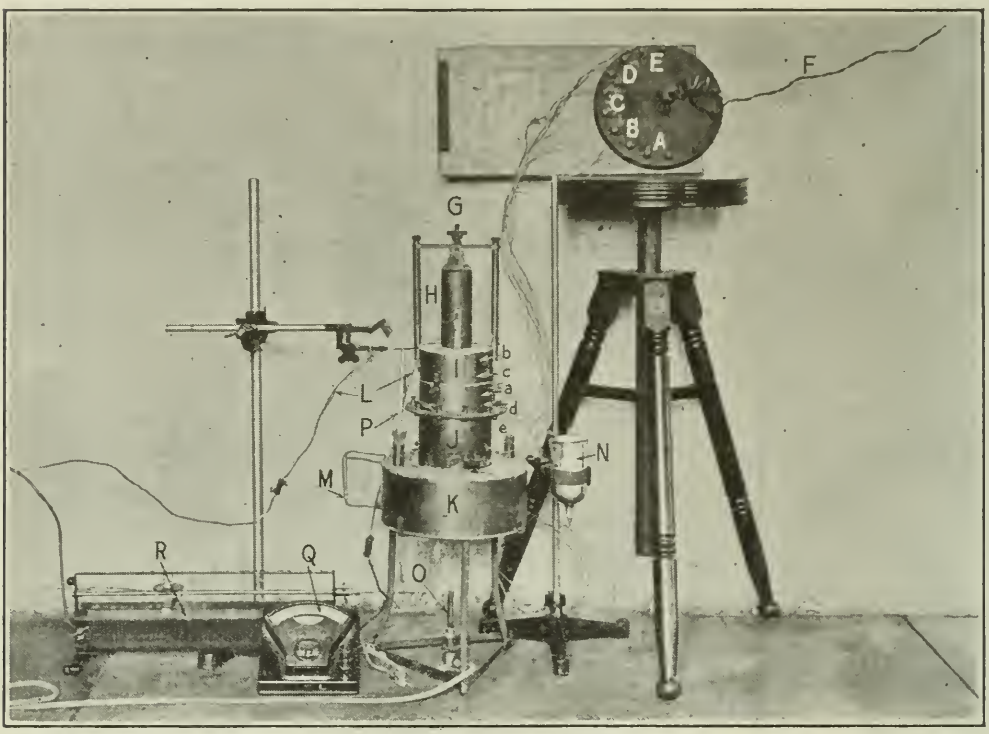
FIG. 1.



in the cases of these two metals. However, as sodium and mercury both *increase* in electrical resistance upon fusion, it seemed desirable to continue our investigation and extend the inquiry not only to other metals but to metals which change in resistance in opposite directions upon fusion. Furthermore, our method appears to us to be one which is not only more extensively applicable but also one which is capable of yielding more precise and certain results than the one above referred to.

While the method which we are about to describe is fully capable of giving the absolute values of the thermal resistivities before and after fusion, we only attempted, in the present investigation, to make an accurate determination of ratios for the reason that time was not available for anything more extensive.

FIG. 2.



DESCRIPTION OF METHOD AND APPARATUS EMPLOYED.

The method in general, which we employed, consists in comparing the temperature gradient between two points in a column of the metal under examination with the temperature gradient between two points of a cylinder of cold-rolled steel shafting. The arrangement provided gave assurance that the quantity of heat flowing per square centimetre between the two temperature-points in the metal being measured and between the two temperature-points in the steel cylinder was nearly the same, and that the heat flow was steady at the time of taking an observation. A full understanding of the method may be best obtained by a careful inspection of the cross-sectional view of the apparatus employed shown in Fig. 1 and the photographic view of the apparatus shown in Fig. 2.

Referring to Fig. 1, various parts which are lettered and numbered are as follows:

1. Spring which allows the metal to expand and contract.
2. Rod supporting heater.
3. Copper cylinder which conducts heat to the metal.
4. Brass casing surrounding heater.
5. Brass frame supporting heater.
6. Kieselguhr heat insulator.
7. Mica insulating sheets.
8. Upper steel cylinder.
9. Metal to be tested.
10. Thermo-elements in metal to be tested.
11. Thermo-elements in lower steel cylinder.
12. Kieselguhr heat insulator.
13. Cover to pan containing boiling water.
14. Rubber hose for conducting steam away from apparatus.
16. Fibrox heat insulator.
17. Brass casing surrounding lower steel cylinder and insulation.
18. Water at 100° C.
19. Supporting tripod.

G, H, I, J, K, M, O, P, a, b, c, d, e, see description of Fig. 2.

Referring to the photograph of the apparatus, Fig. 2, the various lettered parts are as described below.

A, B, C, D, E, a switch for shifting the lead wires *F* to any pair of wires coming from the several thermo-elements *a, b, c, d, e.* There are two binding posts near each letter. Lead wires *F* are connected to the two posts near *C* in the figure.

F, two lead wires running to the potentiometer which measures the potential of the several thermocouples.

G, screw with spring underneath, used to adjust the height of heater *H.* Spring allows heater to rise and fall as metal expands and contracts.

H, electric heater, insulated nichrome wire wound on copper cylinder and covered with brass case.

I, hollow alberene stone cylinder. Hollow part contains the metal to be tested, the upper steel cylinder and two thermocouples, *b* and *c.* Brass casing on the outside.

J contains the lower cylinder of steel. Between this cylinder and the outer brass casing is the kieselguhr heat insulator. This lower steel cylinder contains the thermocouples, *a* and *d*, for measuring the heat gradient in the steel; also an extra thermocouple, *e*, much lower down to test for loss of heat.

K, lower pan containing boiling water.
L, leads carrying direct electric current to heater *H*.
M, glass water gauge showing height of water in pan *K*.
N, Dewar bulb containing ice and thermocouples.
O, Bunsen burner for keeping water in *K* at the boiling-point.
P, thermometer for reading the temperature of water in *K*.
Q, Ammeter for measuring the current passing through heater *H*.
R, Rheostat for controlling current in heater *H*.

Dimensions of Heat-Resistance Apparatus.

Outside diameter of steel guard ring, *J*	5.08 cm.
Inside diameter of steel guard ring, *J*	2.54 cm.
Outside diameter of centre steel rod	1.80 cm.
Length of lower steel cylinder, *J*	21.59 cm.
Length of upper steel cylinder, 8	2.08 cm.
Length of copper heater, 3	12.70 cm.
Diameter of outside brass shell	12.70 cm.
Diameter of lower pan, *K*	25.40 cm.
Diameter of hole for thermocouple in guard ring	0.25 cm.
Diameter of hole for thermocouple in steel rod	0.19 cm.
Distance from top of lower cylinder to upper hole	1.00 cm.
Distance from upper hole to next hole	3.00 cm.
Distance between thermocouples in steel rod	3.00 cm.
Distance between thermocouples in metal used	2.00 cm.
Length of nichrome wire in heater, about	610.00 cm.
Width of nichrome wire in heater	.16 cm.
Thickness of wire in heater, No. 31 B. & S.	
Resistance of heating coil	12.95 ohms
Height of lower pan	10.16 cm.

DATA OBTAINED.

As the reliability and accuracy of the results obtained in this investigation are wholly determined by the consistency and reproducibility shown in the readings taken, we give below in tabulated form the various series of observations just as they were made.

Capital letters, *A, B, C, D,* refer to the lettered studs on the thermocouple switch (see Fig. 2). Small letters, *a, b, c, d,* refer to the corresponding thermocouples (see Fig. 1). Numerals refer to the number of the observation taken under a given set of conditions.

Results obtained for the metal tin follow below:

TIN (Solid).

May 16, 1915

Microvolts — Current, 4.5 ampères

No.	A	B	C	D
1	7618	9481	9205	638
2	7623	9497	9230	645
3	7650	9520	9247	645
4	7655	9533	9248	641

Temperatures computed from above data and thermal resistance compared to steel:

No.	a	b	c	d	Resistance
1	168.08	203.68	198.49	155.55	0.62
2	168.18	203.98	198.96	155.52	0.60
3	168.71	204.41	199.28	156.05	0.61
4	168.80	204.66	199.30	156.23	0.64

Average temperature of tin .... 202° C.
Average temperature of steel 162
Average resistance compared with steel...... 0.62

Microvolts — Current, 4.5 ampères

No.	A	B	C	D
1	7722	9616	9330	660
2	7729	9618	9330	658
3	7728	9618	9335	655
4	7730	9620	9333	653

Temperatures computed from above data and thermal resistance compared to steel.

No.	a	b	c	d	Resistance
1	170.11	206.21	200.84	157.17	0.62
2	170.24	206.25	200.84	157.35	0.63
3	170.22	206.25	200.94	157.39	0.64
4	170.26	206.28	200.90	157.47	0.65

Average temperature of tin .... 204° C.
Average temperature of steel 164
Average resistance compared with steel...... 0.63

Microvolts — Current, 4.7 ampères

No.	A	B	C	D
1	8137	10500	10034	783
2	8192	10538	10072	778
3	8230	10572	10091	783

Temperatures computed from above data and thermal resistance compared to steel.

No.	a	b	c	d	Resistance
1	178.13	222.59	213.99	162.92	.85
2	179.19	223.29	214.69	164.09	.86
3	179.94	223.91	215.04	164.80	.88

Average temperature of tin .... 219° C.
Average temperature of steel 172
Average resistance compared with steel...... 0.86

TIN (Solid)—*Continued.*

Microvolts Current, 4.7 ampères

No.	*A*	*B*	*C*	*D*
1	8443	10733	10197	810
2	8460	10748	10200	810
3	8470	10757	10205	805
4	8475	10751	10203	805
5	8480	10752	10204	805
6	8488	10759	10202	810

Temperatures computed from above data and thermal resistance compared to steel.

No.	*a*	*b*	*c*	*d*	Resistance
1	184.02	226.86	217.00	168.37	.94
2	184.35	227.14	217.06	168.71	.97
3	184.54	227.30	217.15	169.00	.98
4	184.63	227.19	217.12	169.10	.96
5	184.73	227.21	217.13	169.19	.97
6	184.88	227.34	217.10	169.23	.98

Average temperature of tin	222° C.
Average temperature of steel	177
Average resistance compared with steel	0.97

TIN (Molten).

Microvolts Currents, 5 ampères

No.	*A*	*B*	*C*	*D*
1	11628	14705	12680	1495
2	11937	14907	12903	1497
3	11991	15050	12962	1517
4	12026	15100	13022	1518
5	12103	15154	13092	1525
6	12134	15160	13140	1510
7	12152	15190	13146	1507
8	12185	15245	13196	1533
9	12210	15268	13205	1524
10	12226	15275	13218	1508
11	12228	15260	13222	1520
12	12227	15272	13212	1529
13	12238	15287	13223	1522

Temperatures computed from above data and thermal resistance compared to steel.

No.	*a*	*b*	*c*	*d*	Resistance
1	243.13	297.35	261.94	215.76	1.94
2	248.70	300.85	265.88	221.49	1.90
3	249.67	303.28	266.93	222.11	1.98
4	250.29	304.14	268.99	222.74	1.91
5	251.66	305.07	269.22	224.03	1.95
6	252.22	305.17	270.06	224.87	1.93
7	252.52	305.69	270.17	225.25	1.96
8	253.13	306.62	270.29	225.38	1.96

TIN (Molten)—*Continued.*

No.	*a*	*b*	*c*	*d*	Resistance
9	253.58	307.01	271.21	226.00	1.95
10	253.86	307.13	271.44	226.59	1.95
11	253.90	306.88	271.51	226.41	1.93
12	253.88	307.08	271.33	226.23	1.93
13	254.08	307.34	271.52	226.55	1.95

Average temperature of tin .... 285° C.
Average temperature of steel 235
Average resistance compared with steel...... 1.94

May 9, 1916
Current, 5.9 ampères

Microvolts

No.	*A*	*B*	*C*	*D*
1	12238	15305	13232	1527
2	12247	15310	13243	1512
3	12248	15303	13227	1530
4	12243	15330	13240	1520
5	12243	15284	13235	1532
Average	12243	15306	13239	1524

Computed temperatures in ° C. from above data.

a	*b*	*c*	*d*
254.17	307.66	271.81	226.61

Average temperature of tin .... 290° C.
Average temperature of steel 240
Average resistance compared with steel...... 1.95

May 16, 1916
Current, 6.5 ampères

Microvolts

No.	*A*	*B*	*C*	*D*
1	12937	16420	14212	1738
2	12968	16450	14248	1737
3	12990	16475	14293	1743

Computed temperatures and thermal resistances compared to steel.

Temperatures

No.	*a*	*b*	*c*	*d*	Resistance
1	266.52	326.60	288.82	235.36	1.82
2	267.10	327.11	289.46	235.94	1.81
3	267.51	327.53	289.90	236.24	1.81

Average temperature of tin .... 308° C.
Average temperature of steel 252
Average resistance compared with steel...... 1.81

Current, 6.5 ampères

Microvolts

No.	*A*	*B*	*C*	*D*
1	13032	16478	14309	1737
2	13040	16462	14305	1722
3	13044	16450	14314	1718
4	13050	16468	14323	1719

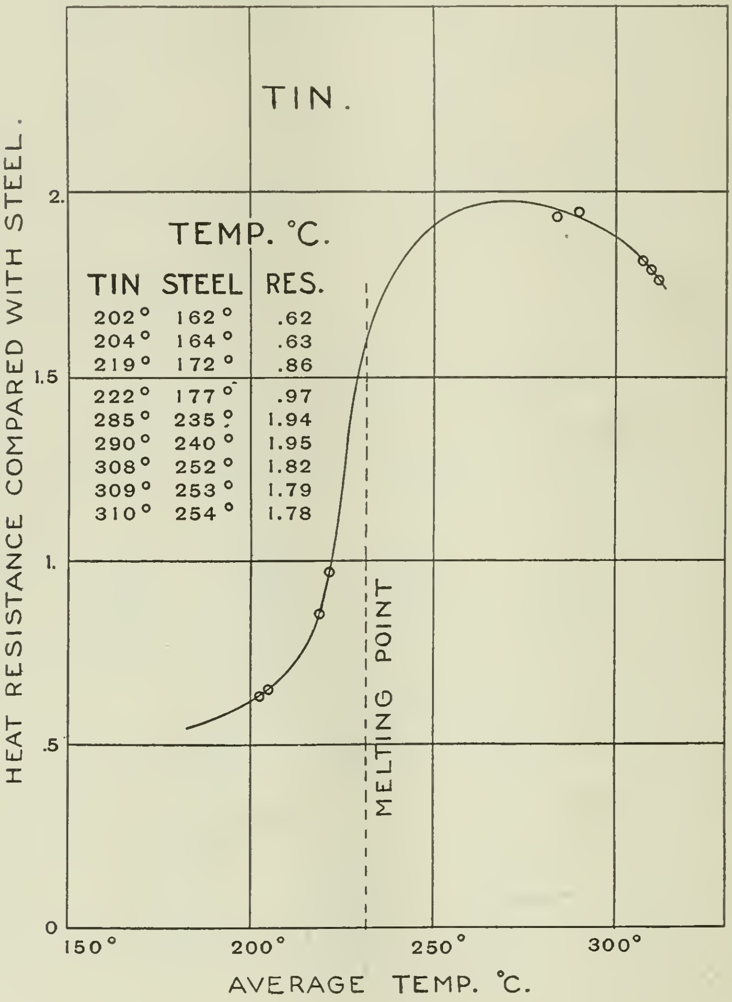
TIN (Molten)—*Continued.*

Temperatures *No.*	*a*	*b*	*c*	Thermal resistance *d*	Resistance
1	268.16	327.58	290.51	237.11	1.79
2	268.30	327.31	290.44	237.53	1.80
3	268.37	327.11	290.59	237.67	1.79
4	268.47	327.41	290.75	237.76	1.79

Average temperature of tin .... 309° C.
Average temperature of steel 253
Average resistance compared with steel...... 1.79

Microvolts *No.*	*A*	*B*	Current, 6.5 ampères *C*	*D*
1	13057	16482	14342	1727
2	13074	16480	14340	1720
3	13072	16470	14332	1720

FIG. 3.



TIN	STEEL	RES.
202°	162°	.62
204°	164°	.63
219°	172°	.86
222°	177°	.97
285°	235°	1.94
290°	240°	1.95
308°	252°	1.82
309°	253°	1.79
310°	254°	1.78

TIN (Molten)—*Continued.*

	Temperatures			Thermal Resistance	
No.	*a*	*b*	*c*	*d*	Re.
1	268.60	327.65	291.08	237.74	1.78
2	268.90	327.61	291.04	238.18	1.78
3	268.87	327.44	290.90	238.14	1.78

Average temperature of tin............. 310° C.
Average temperature of steel............ 254
Average resistance compared with steel.. 1.78

The results of these observations are summarized and embodied in the curve for tin, Fig. 3.

A series of observations obtained for the metal bismuth are presented in the following tabulations:

BISMUTH (Solid).

Microvolts by potentiometer
May 30, 1916
Current, 4 ampères

No.	*A*	*B*	*C*	*D*
1	5923	9207	7325	327
2	5928	9220	7348	333
3	5940	9230	7350	332
4	5949	9230	7344	330
5	5950	9232	7350	332

Computed temperatures for each No. and resistance (thermal) compared with steel.

No.	*a*	*b*	*c*	*d*	Resistance
1	134.35	198.59	162.34	140.97	8.20
2	134.45	198.78	162.79	141.19	8.00
3	134.69	198.96	162.83	141.41	8.07
4	134.87	198.96	162.71	141.56	8.13
5	134.89	199.00	162.84	141.62	8.07

Average temperature of bismuth...... 180.69° C.
Average temperature of steel.......... 137.96
Average resistance compared with steel 8.09

Microvolts
Current, 4.5 ampères

No.	*A*	*B*	*C*	*D*
1	6602	11537	8779	470
2	6618	11552	8813	470
3	6627	11567	8828	470
4	6634	11594	8827	475
5	6650	11614	8844	480

Computed temperatures in ° C. for each No. and thermal resistance compared with steel.

No.	*a*	*b*	*c*	*d*	Resistance
1	148.04	241.49	190.43	157.37	8.21
2	148.36	241.76	191.08	157.68	8.15
3	148.56	242.03	191.36	157.86	8.17
4	148.68	242.52	191.34	158.09	8.21
5	149.00	242.88	191.67	158.51	8.38

Average temperature of bismuth .... 216.62° C.
Average temperature of steel .... 153.23° C.
Average resistance compared with steel.. 8.22

BISMUTH (Molten)—*Continued.*

Microvolts

Current, 4.8 ampères

No.	A	B	C	D
1	7213	12873	9738	640
2	7227	12888	9743	644
3	7244	12883	9754	602
4	7257	12870	9767	603
5	7266	12875	9768	597

No.	a	b	c	d	Resistance
1	160.15	265.35	208.49	172.65	6.82
2	160.42	265.62	208.58	172.99	6.81
3	160.76	265.53	208.79	172.51	7.21
4	161.01	265.30	209.03	172.78	7.18
5	161.19	265.39	209.05	172.84	7.26

Average temperature of bismuth........ 237.13°C.
Average temperature of steel.......... 166.67
Average resistance compared with steel.. 7.06

May 23, 1916

Microvolts by potentiometer.

Current, 5.9 ampères

Thermocouples	A	B	C	D
	9685	17363	13326	1248
No. 1	9885	17395	13352	1260
	10075	17110	13258	1235
	11620	17097	13250	1230
Average	10316	17241	13297	1243
No. 2	10034	17067	13230	1215
	10040	17045	13210	1210
Average	10037	17056	13220	1212
No. 3	10392	17143	13307	1227
	10383	17116	13290	1220
	10389	17127	13285	1224
	10382	17132	13298	1225
	10390	17145	13292	1230
	10384	17156	13300	1228
	10400	17158	13300	1230
	10398	17155	13300	1230
Average	10390	17141	13297	1227

Computed temperatures in ° C., using average potential:

	a	b	c	d
No. 1	219.20	340.41	272.83	196.00
No. 2	214.04	337.30	271.47	191.30
No. 3	220.57	338.73	272.83	197.70

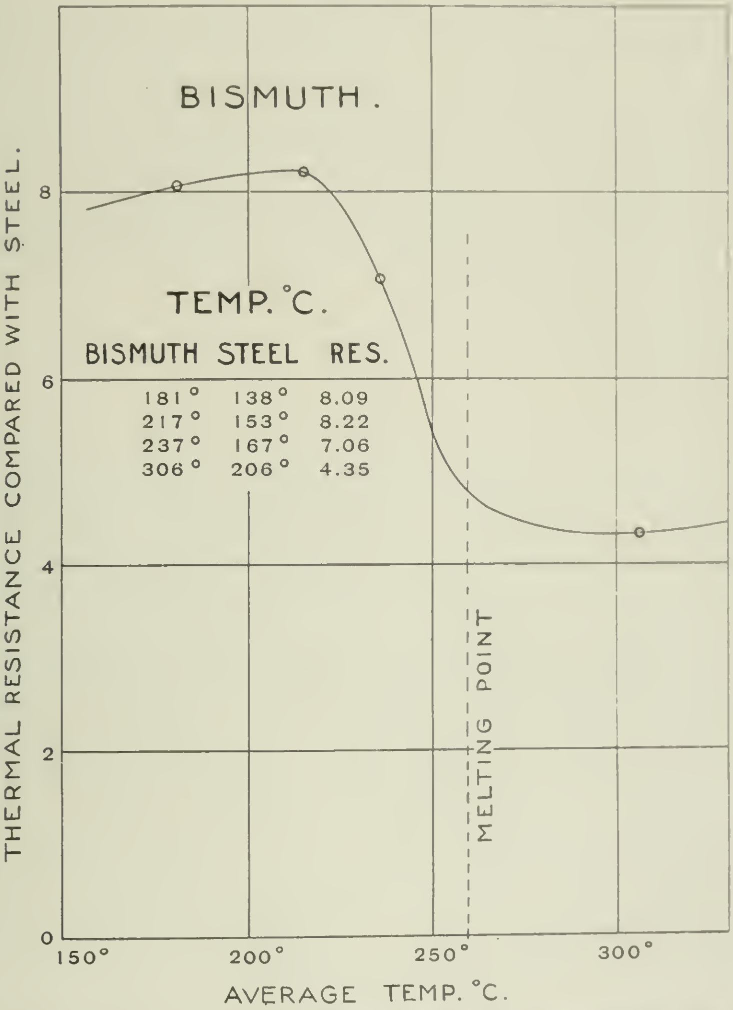
Average temperatures of the bismuth and steel between thermocouples. Thermal resistance compared to steel.

BISMUTH (Molten)—*Continued.*

	No. 1	No. 2	No. 3	Average
Bismuth temperature	306.62	304.36	305.78	305.59
Steel temperature	207.00	202.67	209.13	206.70
Resistance	4.37	4.35	4.33	4.35

These average values at the right give the only point found for molten bismuth. No point closer to the melting-point could have been found, because the melting-point of bismuth is 269° C., and the cooler thermocouple *c* registers only 272°, which shows that the cooler part of the bismuth was just above the melting-point. No point at a higher temperature could be found, because the nichrome wire used in the heater was at a bright red heat to obtain the above. Any higher temperature would have melted the wire.

FIG. 4.



The curve for bismuth (Fig. 4) summarizes and embodies the observations given in the above tabulations.

A detailed description of the many precautions and arrangements employed to insure accuracy would be beyond the limits of our space for this article, but we can assure those interested that all the observations were taken with extreme care, and we feel certain that no errors of any considerable magnitude have crept into the observations. The conclusion, therefore, is inevitable that the thermal resistance characteristics for both tin and bismuth, when these metals pass from the solid into the molten state, are substantially the same as the electrical resistance characteristics, and therefore we can assert that the Wiedemann-Franz ratio holds, at least to a first approximation, when the metals tin and bismuth pass through a change of state. As the same was found to be true by other observers for the metals mercury and sodium, the presumption is strong that the same is true for other metals which have not yet been examined.

Palmer Physical Laboratory,
Princeton, N. J.,
May, 1917.

The Air-cooled Automobile Engine. Anon. (*The Autocar,* vol. xxxix, No. 1145, p. 311, September 29, 1917.)—Whatever may be said about the heavier cars, air-cooling will always possess a special attraction for the designer of light cars. It diminishes weight, it reduces the cost of manufacture, and it simplifies upkeep. Air-cooling, as has been repeatedly pointed out, is making great strides, thanks to aviation; cylinder distortion is being eliminated; cooling is being improved by better material and sounder constructional methods, and weight is being reduced in an almost incredible ratio.

Of all types of air-cooled engine, the radial is possibly the most attractive. It can be mounted at the extreme nose of the chassis, where it will not be unsightly and where all of its cylinders will get an even cooling blast with a fan on the reverse side if necessary. Its short crank-shaft and other constructional details endow it with amazing power-to-weight ratios. Already we have a flat air-cooled twin engine at three pounds per horsepower. The radial engine is extremely shallow, and would allow the car builder an extra two feet of space along the chassis. There is no need for the large number of cylinders used in air propulsion to secure a satisfactory balance. A 20-horsepower, 800-pound vehicle is probably practicable. The type is perhaps suited only to comparatively low horsepowers, as the crank-shaft centre would come too high up if the cylinder were at all large.

THE DETERIORATING ACTION OF SALT AND BRINE ON REINFORCED CONCRETE.*

BY

HENRY JERMAIN MAUDE CREIGHTON,

Department of Chemistry, Swarthmore College.
Member of the Institute.

At the present time, when concrete structures are being erected throughout the country for all manner of purposes, it is of the greatest importance that the limitations, the durability, and the causes of the deterioration of reinforced concrete should be thoroughly understood. Within the past few years the number of reinforced concrete structures has been increasing so rapidly that to-day concrete has replaced brick and stone to a large extent. Since most of our oldest reinforced concrete is not over fifteen to eighteen years old, who can predict, from so short a period of observation, its condition twenty-five or fifty years hence?

During the past few years there has been considerable discussion regarding the durability of concrete, and there exists a certain amount of disagreement on the matter. There appeared in *Engineering News* of April 4, 1912, wherein is published a report of the American Society for Testing Materials' meeting, the following sentence: "The report of the water-proofing committee brought about some excited discussions, during which several persons affirmed their belief in the imperishability of concrete and protested against any hint of any other possibility." However, though "it is no doubt true that many diseases can be cured by a practitioner who strenuously denies their existence and thus encourages the patient to resist and overcome them, it can hardly be expected that defective concrete walls or disintegrating piers can be strengthened by 'absent treatment,' however vigorous be the denial of the injury or however prominent the denier." It is much better to look facts in the face and attempt to find a remedy.

Sea-water, one of the agents which brings about the disintegration of concrete, attracted the attention of users of cement soon after it was first employed in marine construction. Although a great deal of non-reinforced concrete has withstood the action of the sea up to the present, and will probably continue to do so, still some of it has failed. Although the cause of this disintegration is not definitely known, Le Chatelier and others point out [1] that it can probably be ascribed to a reaction between the magnesium sulphate of the sea-water and the lime of the cement (formed during setting) and the alumina of the aluminates of the cement, the result being the formation of magnesium hydrate and calcium sulpho-aluminate, which crystallizes with a large number of molecules of water. Notwithstanding that the other components of sea-water have usually been considered as having little effect on concrete, attention has recently been called to the fact that both sodium chloride and magnesium chloride rapidly react with the silicates in concrete.[2]

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* Communicated by Professor Creighton.

In the laboratory it is possible to destroy, almost completely, small cylinders or other forms of concrete or cement mortar by the action of solutions of various salts. The "Action of the salts in alkali water and sea-water on cement" has been the subject of a lengthy investigation by Bates, Phillips and Wig, of the U. S. Bureau of Standards, and their results have been published [3] under the foregoing title. This investigation was undertaken in consequence of disintegration of concrete, through the action of water containing magnesium and sodium sulphates, occurring in several irrigation projects in some of the Western states; and for the purpose of determining the action of various single and mixed salt solutions on concrete and cement. The salt solutions were allowed to percolate through hollow cement cylinders closed at one end, and it was found that any cement mortar may be destroyed if a sufficient amount of salt accumulates and crystallizes out. It was also found that, in general, chloride solutions were more active than sulphate solutions in removing lime from concrete, but that mixed chloride and sulphate solutions were more active than solutions of single salts.

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[1] Le Chatelier, *Tonindustrie Zeitung*, 33, 931; Chandlot, "Ciments et Chaux Hydrauliques," p. 306; Michaelis, *Bul. de la Soc. D'Encourag. de l'Ind.*, June, 1897.

[2] Chandlot, *loc cit.;* Michaelis, *Bul. de la Soc. D'Encourag. de l'Ind.*, 682, 1890; D'Rohan, *Eng. Record,* July 20, 1910.

[3] Bur. of Standards, Techn. Paper 12, JOUR. FRANKLIN INST., 175, 65.

According to a recent report[4] by J. L. Harrison, District Engineer, Iloilo, the cracking of reinforced concrete structures is markedly prevalent in the Philippine Islands. A study of this trouble has shown that not a single structure showing rusted steel has been free from salt, the percentage of which varies considerably. In view of this, engineers in the Philippines have been advised that not only is the use of salt water dangerous in concrete structures, but that beach sand and beach gravel should be employed only after having been thoroughly washed with fresh water.

The foregoing, and many other similar pieces of evidence, indicate that salt and brine exert a deteriorating action on concrete.

In this paper the writer wishes to give a brief account of observations on the deterioration of reinforced concrete by salt and brine, which were made by him, a few years ago, while examining a large number of reinforced concrete structures in different parts of the country.

In order that the deteriorating action of salt water on iron may be better understood, the probable reactions which occur when this metal comes in contact with a salt solution will be briefly discussed.

When a piece of iron is placed in distilled water, it becomes negatively charged, since its electrolytic solution pressure (which is equal to 1.2×10^4 atmospheres) causes atoms of the metal to pass into solution in the form of positively charged ions, leaving an equivalent number of negative charges behind on the bar of metal. In spite of the large electrolytic solution pressure of iron, only a vanishingly small quantity of it passes into solution in the form of ions, and, consequently, the bar of metal receives but a very small negative charge. This is due to the fact that when a ferrous-ion with its large positive charge ($2 \times 96,500$ coulombs for every gramme-ion of the metal) leaves the bar of neutral metal the latter acquires a correspondingly large negative charge; it therefore becomes more difficult for a second ferrous-ion to go into solution, owing to the attraction between the unlike charges; and it is still more difficult for a third ion to leave the metal, and so on. Very soon, therefore, the negative charges upon the bar of metal become sufficient to prevent further ferrous-ions from going into solution, and equilibrium occurs; and, unless these negative charges are removed from the metal, no more iron can pass into solution. Suppose, now, that common salt be added to the water containing the bar of iron. On dissolving, this electrolyte largely dissociates into its ions, and it may be assumed that hydrolysis takes place, although to a most limited extent, in accordance with the equation:

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[4] *Bulletin* of the Bureau of Public Works, October, 1916.

$$NaCl + H_2O \rightleftarrows NaOH + HCl.$$

The concentration of these new substances being extremely small, they dissociate practically completely and give rise to negatively charged hydroxyl ions and positively charged hydrogen ions:

$$NaOH \rightleftarrows Na^+ + (OH)^-,$$

$$HCl \rightleftarrows H^+ + Cl^-.$$

The hydroxyl ions then unite with the ferrous-ions, that have passed into solution from the bar of metal, to form undissociated ferrous hydroxide:

$$Fe^{++} + 2(OH)^- \rightleftarrows Fe(OH)_2,$$

which gradually precipitates as an hydrated oxide. The presence of dissolved oxygen in the solution would, of course, gradually convert the oxide and ferrous hydroxide into the corresponding ferric compounds.

The negative charges upon the bar of iron, which were in equilibrium with the ferrous-ions before the addition of the sodium chloride, now attract the positively charged hydrogen ions, the electrolytic solution pressure of hydrogen being much less (9.9×10^{-4} atmospheres) than that of iron and very much less than that of sodium ($> 10^{43}$ atmospheres). In consequence of this attraction, hydrogen ions move towards the negatively charged iron bar, touch it and become neutral, gaseous hydrogen atoms. The negative charges on the bar being thus diminished, more iron enters the solution in the form of ferrous-ions, and the foregoing process occurs again, and so on. In this way the bar of iron gradually disappears and iron oxide and hydrated oxide accumulate.

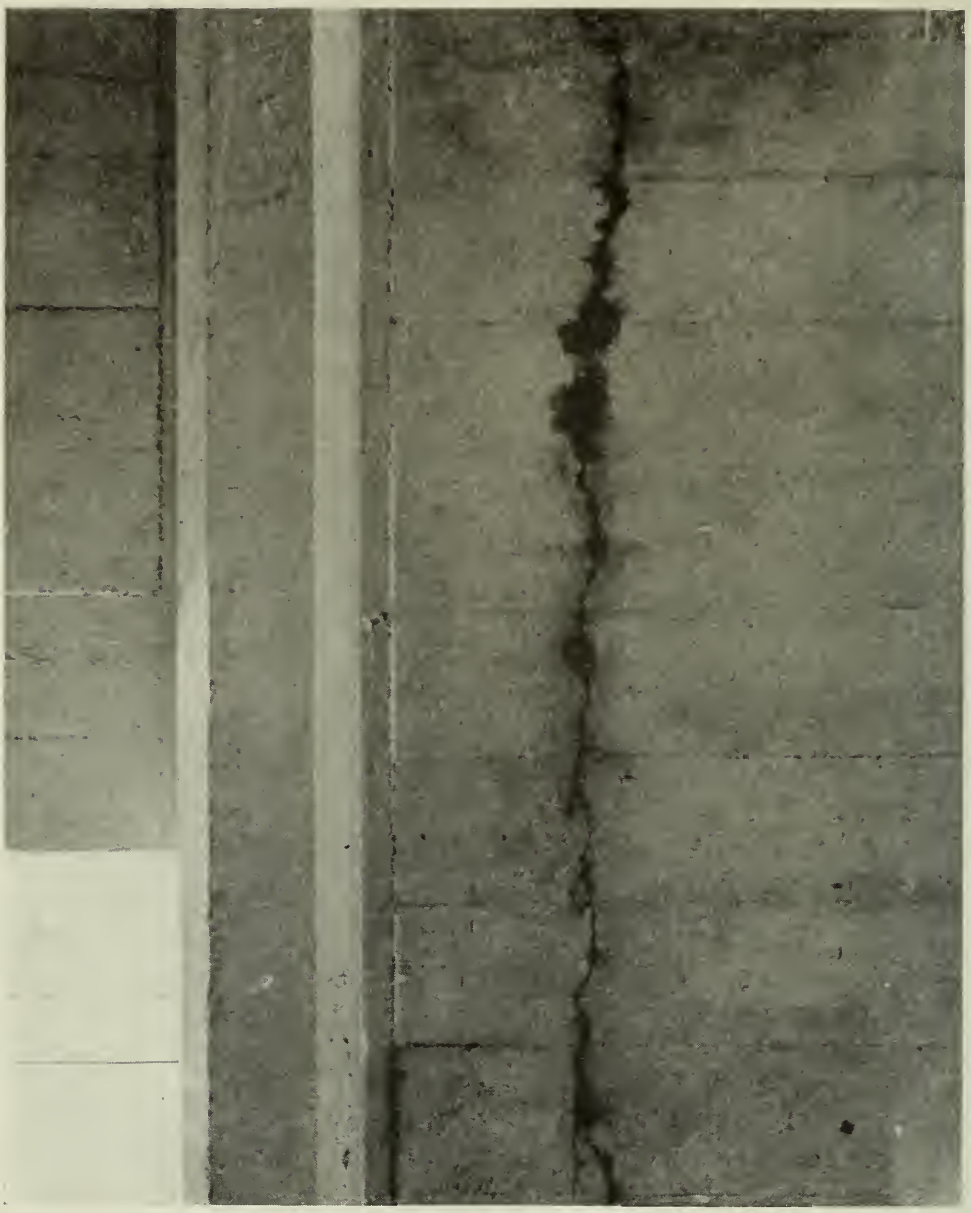
The nascent hydrogen which is produced on the bar may be absorbed by the iron; it may be oxidized by the oxygen dissolved in the solution, or it may be liberated as a gas. In order to determine whether gaseous hydrogen is ever liberated under the foregoing conditions, the writer immersed a number of pieces of iron in dilute aqueous solutions of sodium chloride contained in glass tubes with a capillary top, and connected at the bottom with a small glass tube bent upwards at right angles. Before being introduced into the glass tubes, the salt solution was boiled to remove the air, and afterwards, before sealing off the tip of the capillary, a high vacuum was applied to the solution for some time. It was found that in all the tubes a grayish-green deposit slowly accumulated near the bottom, and at the end of several months a small quantity (0.1 to 0.2 c.c.) of gas had formed in three of the tubes. This gas proved to be mostly hydrogen.

In addition to the corrosion of iron through the action of brine by the processes just outlined, auto-electrolysis may occur on account of the presence of segregated impurities which are responsible for the differences of potential established in certain areas. These potential differences bring about a galvanic action which causes the iron to go into solution at certain points with the formation of rust.

From what has been said, it is clear that reinforced concrete which comes in contact with brine or sea-water, unless rendered absolutely impervious, will commence to deteriorate as soon as the brine comes in contact with the reinforcing rods; for, as both iron oxide and the hydrated oxide occupy a larger volume than the corresponding amount of iron, there will be developed an enormous expansive force which is sufficient to crack the strongest concrete and force it away from the reinforcing rods. The more porous the concrete, the more rapidly will this action take place. Indeed, the writer is familiar with cases of cinder concrete structures, in contact with brine, which have shown signs of advanced deterioration at the end of a year.

Regarding the water-proofing of concrete, it should be pointed out that an impervious concrete is probably never obtained outside the laboratory. The average concrete is practically never water-proof. Although there are many substances on the market for rendering concrete water-proof, the majority of them is far from satisfactory. A number of such instances has been investigated by Brown,[5] who points out that all waterproofing materials will sooner or later hydrolyze, crack, or disintegrate.

FIG. 1.



Since most concrete is more or less porous to moisture, and since iron undergoes gradual decomposition, in the presence of salt water, with consequent expansion in volume, it is to be expected that reinforced concrete which comes in contact with brine or salt and moisture will ultimately disintegrate. It is not surprising, therefore, to find throughout the country reinforced concrete piers, sea walls, and buildings in the neighborhood of the ocean in various stages of deterioration. The cracks which occur in such concrete usually run parallel to the reinforcing rods. These cracks are very narrow at first, but as the decomposition of the iron progresses they become iron-stained, gradually increase in width, and, finally, the concrete is forced so far from the reinforcing rods by the pressure of the accumulating iron oxide that large pieces of it break off.

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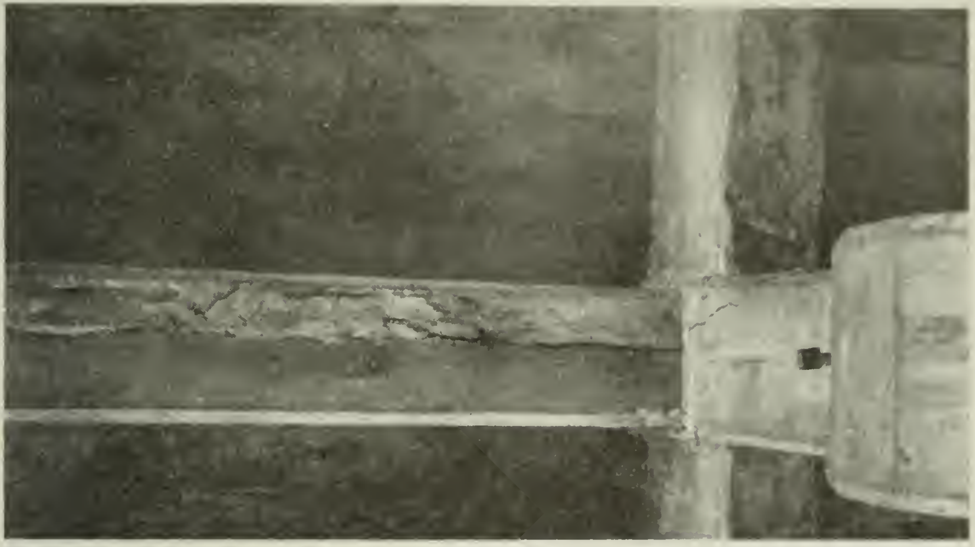
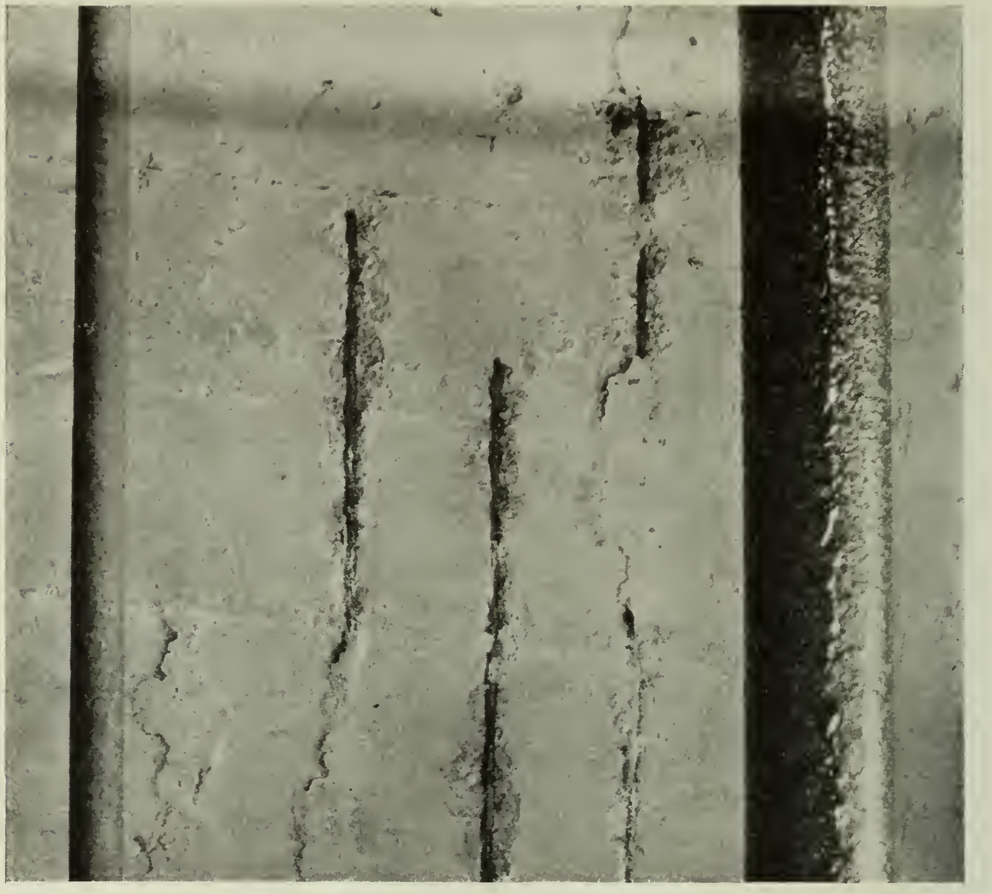
[5] *The Electrician,* 69, 915 (1912).

FIG. 2.



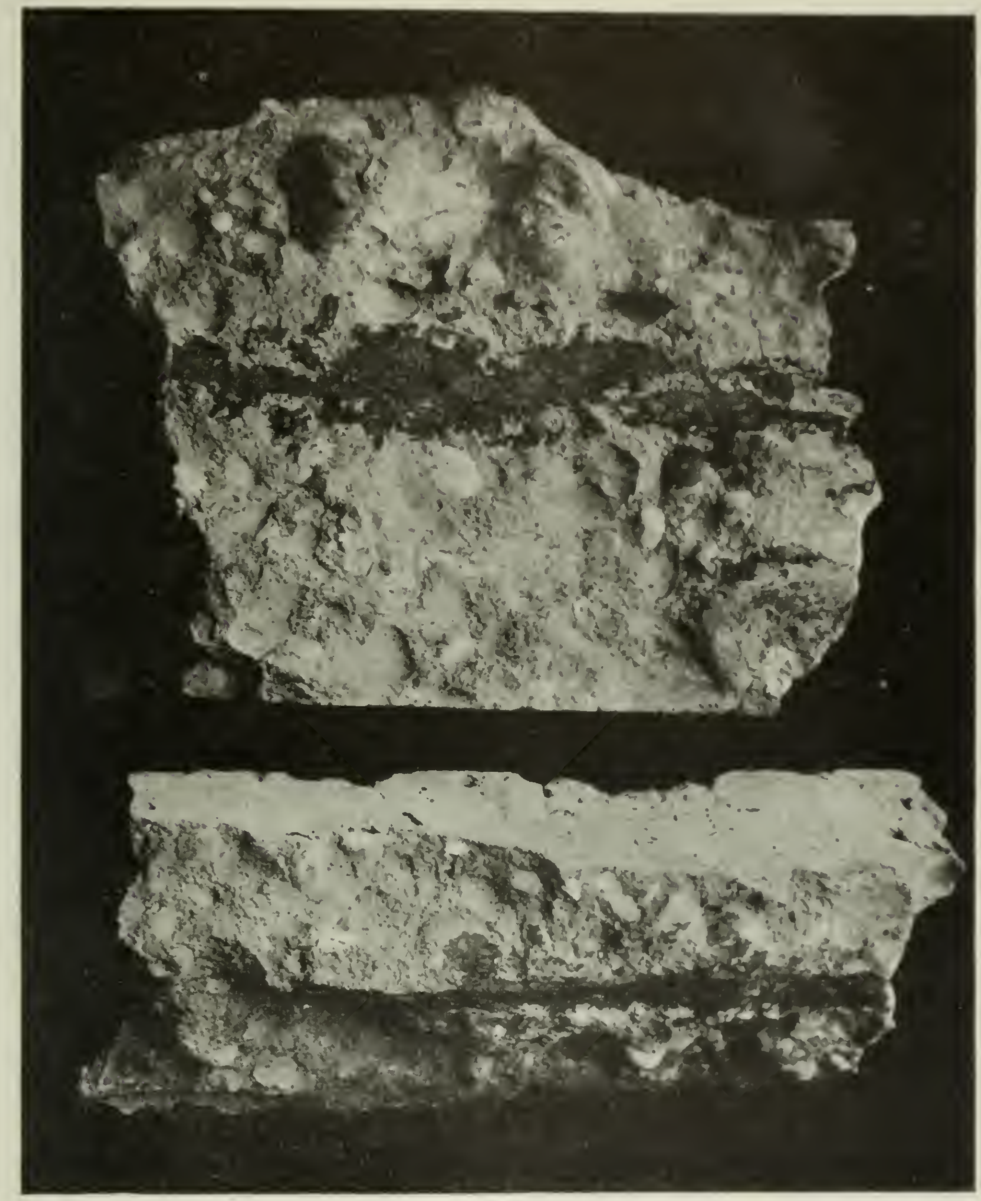
In many parts of the country to-day there are reinforced concrete structures housing industries that use large quantities of salt and brine, which are constantly spilled on the floors. In order to ascertain whether the concrete of such buildings has undergone any deterioration, the writer a few years ago examined a large number of them in different cities throughout the country. In practically all the buildings inspected, reinforced concrete floors which came in contact with brine had iron-stained cracks on the under side. Usually these cracks were very narrow, but they indicated, nevertheless, deterioration of the reinforcements, and would continue to grow as the disintegration of the iron progressed. Fig. 1, which is a photograph of the ceiling of a large reinforced concrete building in Detroit, the floors of which are continually wet with brine, is a typical example of one of these iron-stained cracks in the early stages, and Fig. 2 shows a cracked horizontal beam supporting the floor of a reinforced concrete building in Chicago. In many instances the cracks were found to vary from ⅛ to ¼ inch in width, and in some cases deterioration had progressed so far that large pieces of concrete had fallen, or were about to fall, leaving the badly corroded reinforcements exposed, as illustrated by Fig. 3 (photograph taken in Buffalo). An examination of a number of pieces of this fallen concrete showed that in every case a quantity of iron oxide adhered to the concrete where it had come in contact with the reinforcing rods (Fig. 4), and that it was sometimes as thick as ⅛ inch. Where the concrete had broken away from the reinforcements, the latter were usually so badly corroded that it was possible to remove thick layers of oxide with the fingers. In a few cases the deterioration had progressed to such an extent that the rein-

FIG. 3.



forcements had been completely converted into oxide. Fig. 5 shows pieces of iron oxide, $^1/_8$ to $^3/_{16}$ inch thick, which were pulled away from corroded reinforcing rods or beams with the fingers.

FIG. 4.

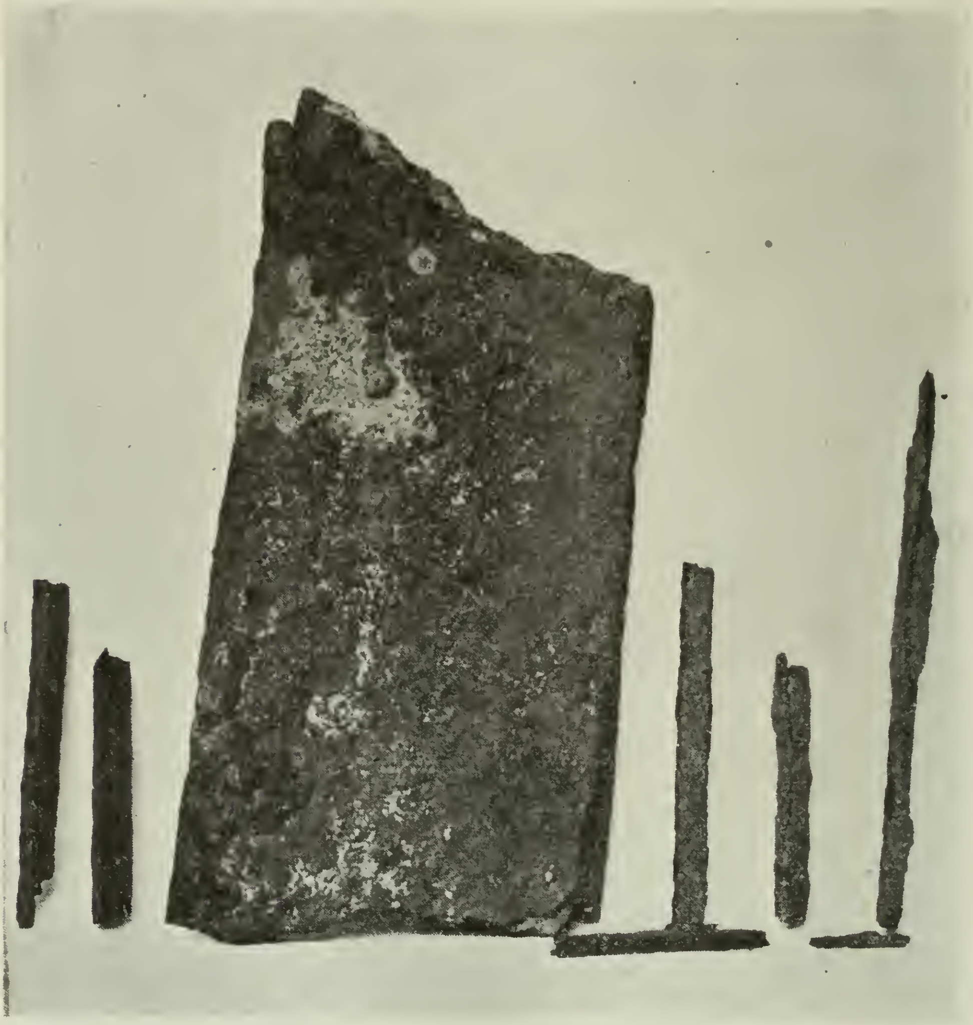


A few details regarding particular cases of deterioration met with in some of the reinforced concrete structures examined may be of interest.

The ceiling of a machine shop of a large reinforced concrete plant in East St. Louis was found to be very badly damaged.

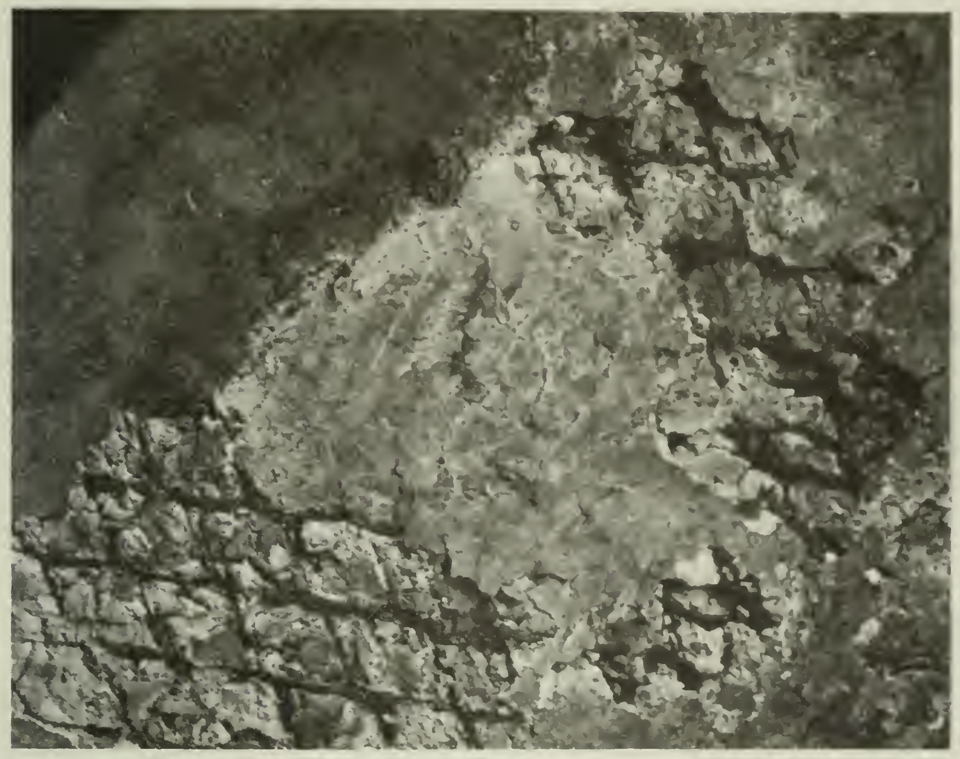
This building, at the time of inspection, was about ten years old. The upper side of the ceiling was continually wet with brine, which constantly leaked through to the under side and wetted it in a number of places. On this ceiling large, brown iron-stains were numerous and in at least twenty places pieces of concrete had fallen, leaving badly corroded, net-iron reinforcements exposed. In one place a piece of concrete twelve feet long and varying from two to eighteen inches in width had broken away. The reinforcements of this ceiling were imbedded at a depth of about ¾ inch from the surface. Photographs of this ceiling are shown in Figs. 6, 7 and 8. Examples similar to these have been observed by the writer in Chicago, Kansas City, Detroit, and Buffalo.

FIG. 5.



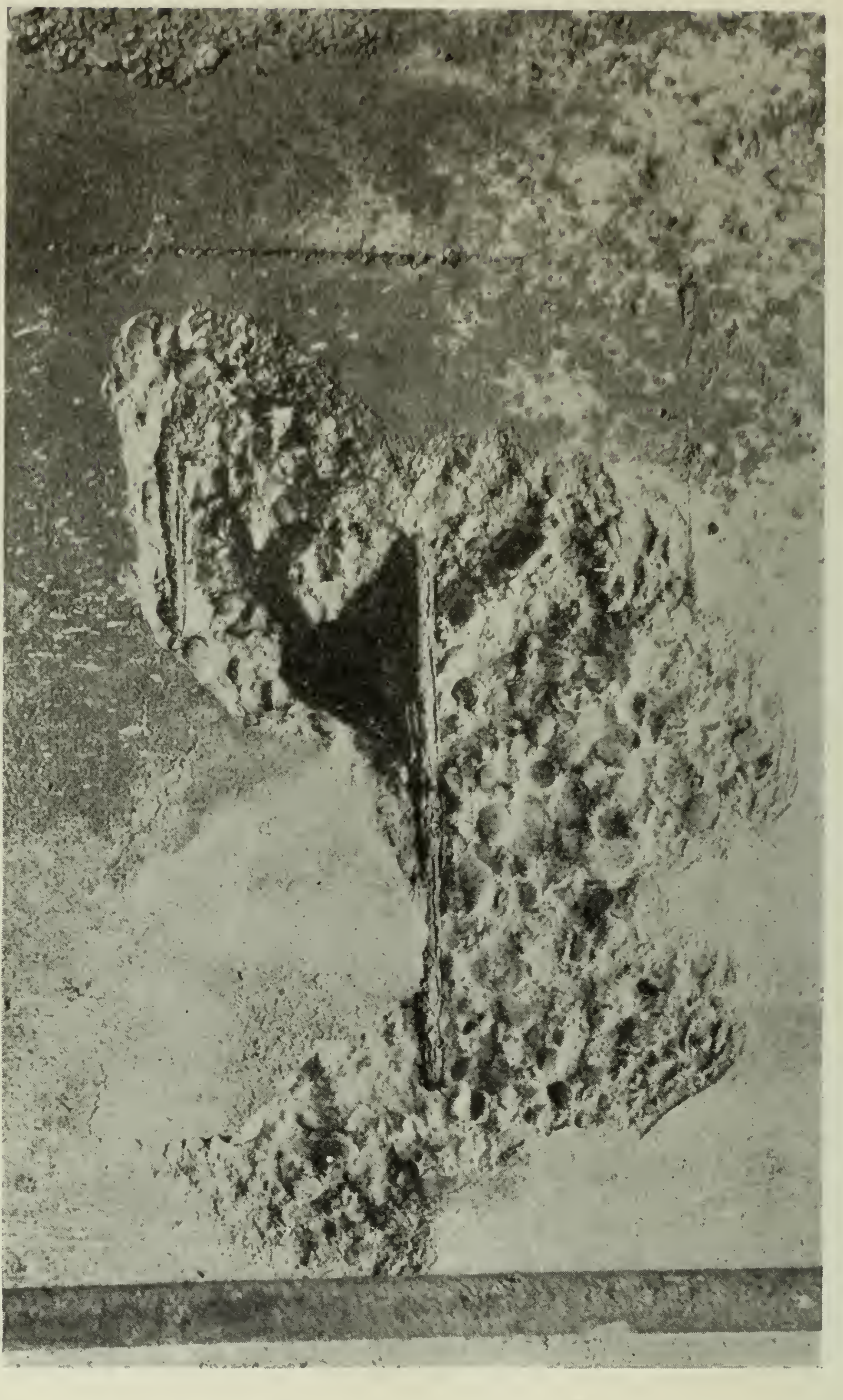
At a plant in Kansas City there was found a very interesting cracked reinforced concrete pillar which supported a reinforced concrete platform at the top of an outside staircase. Large quantities of salt were used in the plant, and the platform was often wet with brine. The cracks on the pillar ran parallel to the longitudinal reinforcing rods. In some places the concrete had fallen away from the rods, which were badly corroded, and in others portions of the concrete were easily pulled away. A photograph of this pillar is shown in Fig. 9.

Fig. 6



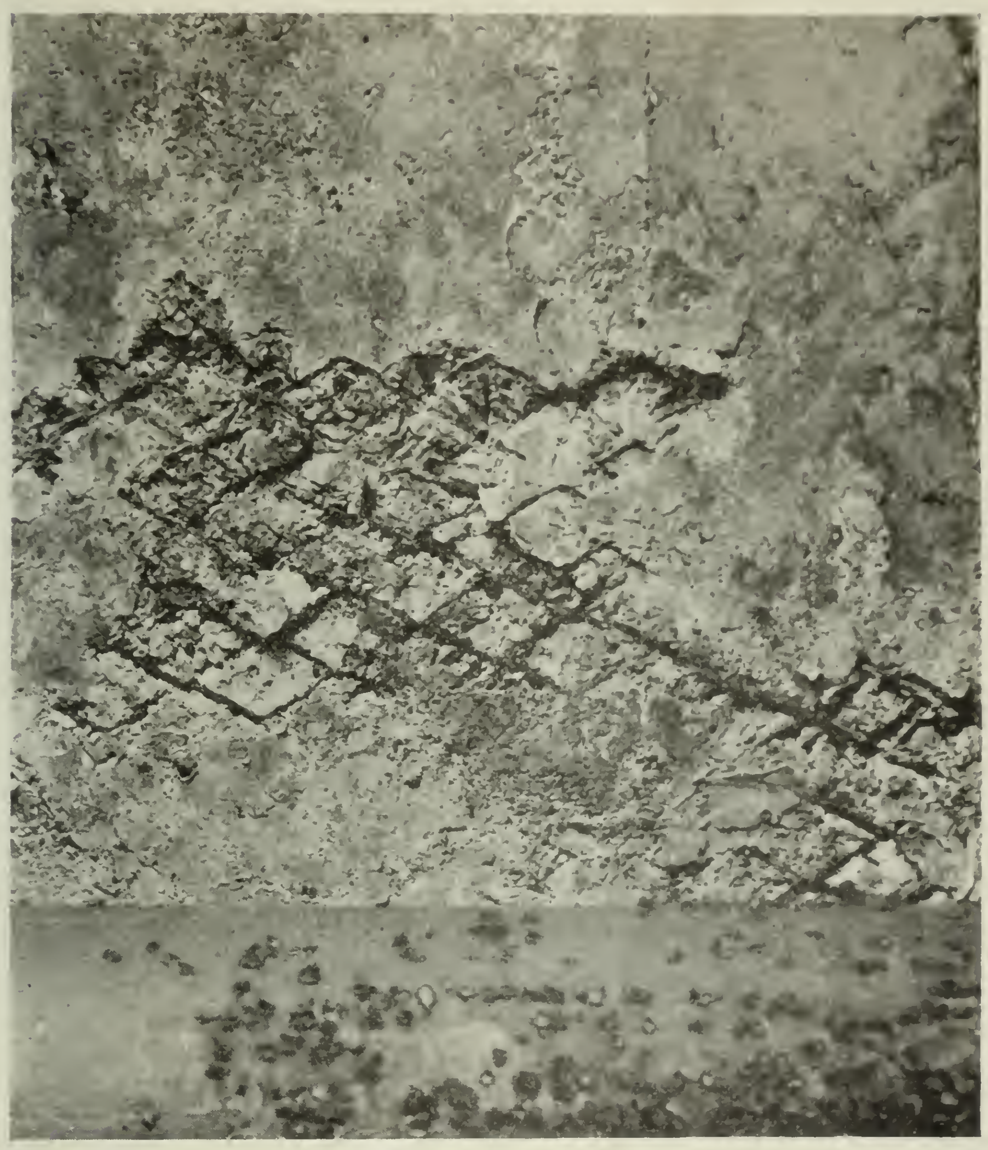
At another plant in this city there was a long outside platform, from which cars were loaded, covered by a reinforced concrete roof. At one end of this roof there was a pile of rock salt, which was partially protected from the weather by a wooden roof. Rock salt had been stored in this place for years. For a number of yards beyond where the salt was stored it had been spilled continually on the concrete roof, and, owing to rains, perhaps a quarter of the roof was frequently wet with dilute brine. On the under side of the roof, directly below this place, there were many brown iron-stains, wet patches, salt deposits, and in one place

FIG. 7.



the concrete had fallen, leaving the net-iron reinforcings exposed. These had deteriorated to such an extent that the outer portions crumbled on touching and some of the rods were easily pulled away. The area from which the concrete had fallen was at least one square foot. The individual rods of the exposed net-reinforcing, originally about ⅛ inch in diameter, had increased to about ¼ inch in diameter, owing to the conversion of the iron into oxide. Some of these rods had disintegrated to such a degree that the sound iron core was less than $^1/_{25}$ inch in diameter. Near where the concrete had fallen, it was evident that

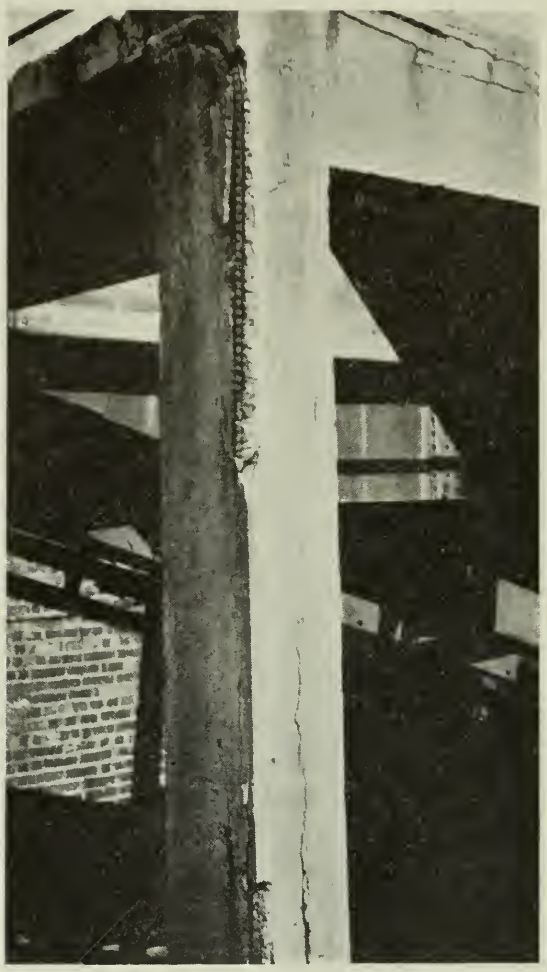
FIG. 8.



the expanding reinforcings were gradually forcing the concrete downwards. At the far end of the ceiling, where salt had not been spilled above, there was no evidence of deterioration and the concrete was in an excellent condition.

At a third plant in Kansas City, a five-year-old, reinforced concrete, basement ceiling was found to be in a very bad condition. This ceiling was reinforced with ¾-inch twisted iron rods. The floor above was more or less wet all the time, and, in places, salt came in contact with the water, forming brine. There were many cracks on this ceiling, some of which were sufficiently wide to insert a lead-pencil. One such crack was twenty to thirty feet in length. In several places large pieces of concrete had fallen, leaving corroded reinforcements exposed.

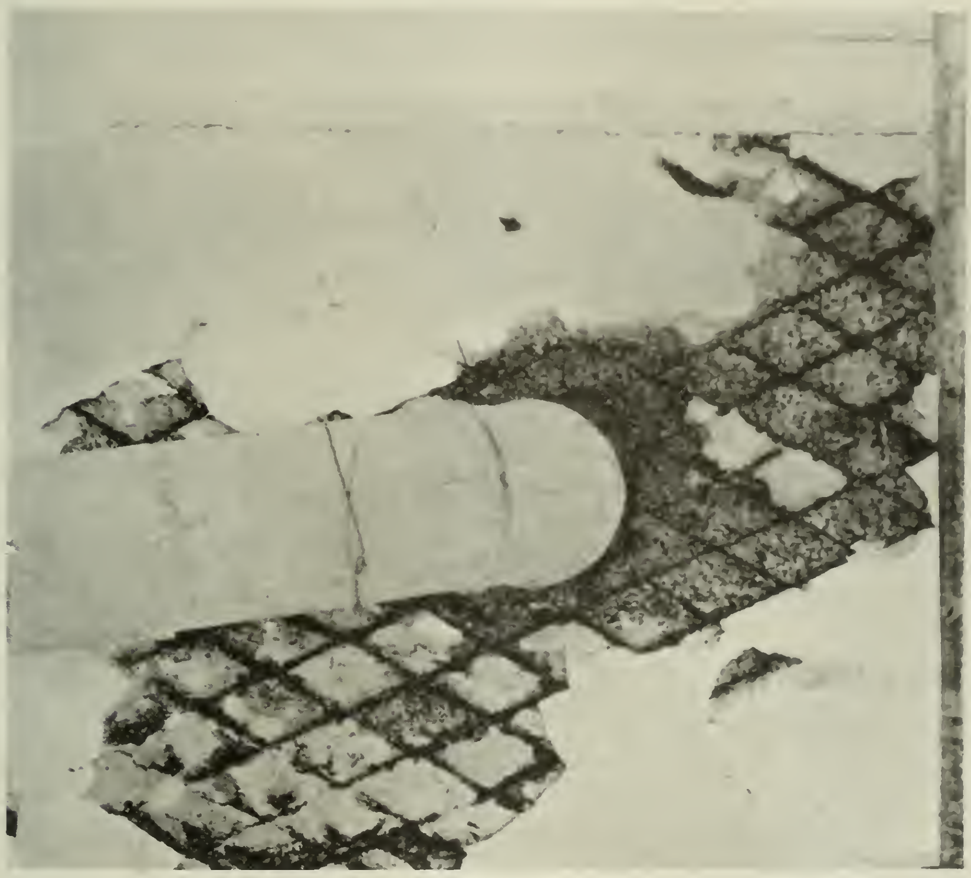
FIG. 9.



In one place a large piece of concrete which was almost dropping and which weighed about twenty-five pounds was easily pulled away from the reinforcements. The under side of this, as is usually the case, had a large portion of the corroded reinforcements adhering to it.

The writer examined a building in Kansas City which contained a large quantity of reinforced cinder concrete that came into contact with considerable amounts of brine. This concrete, which was thirty years old, was in a very damaged condition, and in many places very large pieces had fallen.

FIG. 10.



In one of the Chicago plants examined, a whole floor had collapsed about a year previously, owing to the weakening of the reinforcements by disintegration.

Similar cases to the foregoing have been found by the writer in a number of cities in different parts of the country. An excellent example of deterioration of reinforced concrete found in Buffalo is shown in Fig. 10.

When concrete construction is carried out in winter, it is sometimes the practice to add salt to the concrete to prevent freezing, often as much as twenty per cent. being added. The writer has examined a number of reinforced concrete structures where salt had been mixed with the concrete during construction. As is to be expected, where the concrete comes in contact with water or moisture, there are manifold evidences of deterioration; but, on the other hand, where the concrete has been kept dry no damage has been observed.

The following conclusions are drawn by the writer from his investigations of the action of salt and brine on reinforced concrete:

1. All concrete which is not water-proofed in some way is more or less porous to water and brine.

2. Brine readily softens the surface of concrete and, therefore, more easily penetrates to the reinforcements, on which it exerts a disintegrating action that, owing to the attendant expansion, gradually weakens the concrete, causing it to crack and split, and in some cases to fall away from the reinforcements.

3. The more porous the concrete, the more rapid the disintegration of the reinforcements through the action of brine.

4. Reinforced concrete floors which come in contact with brine will gradually develop leaks. These will be followed by incrustations of discolored salt on the under side, where, later, iron-stained, hair cracks will develop running parallel to the reinforcements. As the deterioration progresses, the cracks will widen and, owing to the great expansive force of the accumulating iron oxide, the concrete will be gradually pushed from the corroded reinforcements and ultimately fall.

DEPARTMENT OF CHEMISTRY,
Swarthmore College,
July 27, 1917.

THE PHYSICAL CHARACTERISTICS OF THE ELEMENTARY GRAINS OF A PHOTOGRAPHIC PLATE.*

BY

MILLARD B. HODGSON.

When we speak of "grain" in a photographic plate, we generally use the term in a rather loose sense. We employ it to denote, in a general way, both the characteristics of the individual granular deposits of silver and the arrangement or agglomeration of these constituent particles, as an entirety, with sometimes emphasis on one phase of the subject and sometimes on another.

It is the purpose of the present paper to sharply differentiate between these two phases by outlining a few fundamental conceptions of plate grain; also to present some of the more interesting data obtained in the study of the elementary particles of a silver halide emulsion.

There are present, in nearly all developed and dried photographic plates, deposits of silver of varying size and shape. On close examination it is found that these deposits are made up of small elementary units, which in a high-speed plate negative vary in size, from the ultra-microscopic to five or six microns in greatest dimension, the average variation being from 0.2 μ to 4 or 5 μ, and the mean size about 2.5 μ.

Fig. 1 shows a photomicrograph of a section of a high-speed photographic negative, illustrating these elementary units. These elements are grains in the strict sense of the term, for, as will be shown later, they are inherently conditioned in position and size by the position and size of the original silver halide grains. That is, they are to a certain extent isolated from each other by intervening walls of gelatine.

In viewing a dried down negative, however, by transmitted light, under moderate magnification, or none at all, we see not these isolated grains, but, in effect, agglomerations of grains by the projection of light through interstices between many grains in numerous "grain planes" throughout the emulsion layer. Therefore since the average layer is about six grains deep, and since the grains themselves are distributed on a probability basis in each layer, we obtain more or less regular large patches and chains of grains as a result, the pattern and regularity depending on the particular type of emulsion used.

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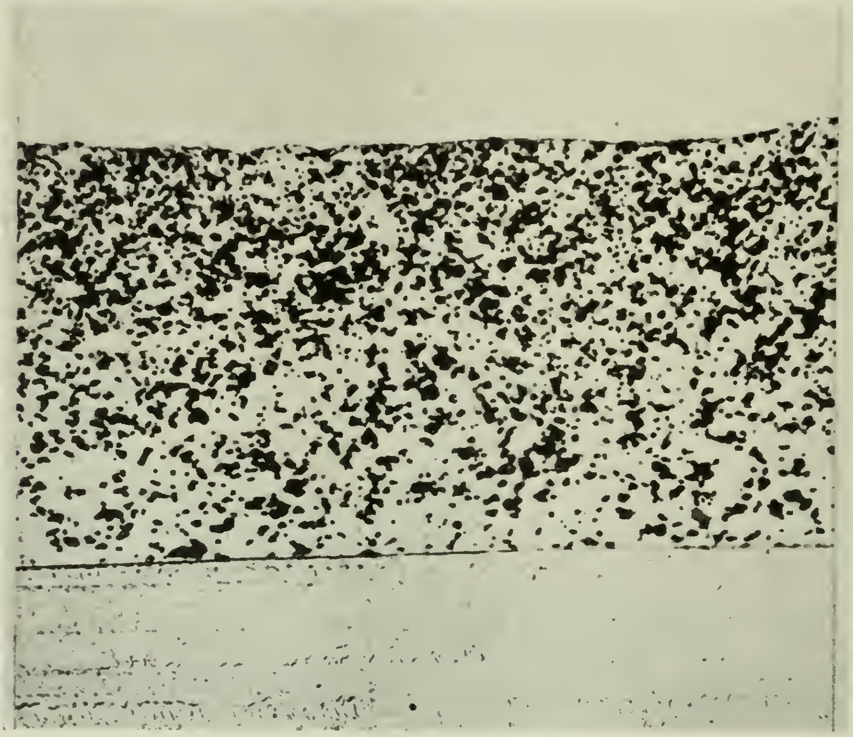
* Communicated by Dr. Mees. Communication No. 56 from the Research Laboratory of the Eastman Kodak Company.

It is this granularity which makes up what is commonly meant in speaking of grain. It is the grain met with in projection work, in enlarging and in portraiture.

FIG. 1.



Section showing individual silver grains. Magnification, 350 diameters.

This overlapping and agglomerating of grains can be seen nicely by observing a horizontal plane view of a photographic film through the entire emulsion, in comparison with a thin vertical section through the same film (Fig. 2).

It is not the purpose of this paper to discuss the matter of plate granularity, meaning agglomeration of individual grains, which phase of the subject is now the subject of investigation in this laboratory.

As has been stated, the physical characteristics of the developed elemental grains depend largely upon the characteristics of the elemental silver halide grains.

Silver bromide occurs, in the average emulsion, in the form of more or less regular semi-transparent crystals belonging to the isometric system, the most regularly recurring figure being the tetrahedron. The larger grains are evidently builds or aggregates of hemihedral tetrahedra or other imperfectly developed forms. In addition there are present numerous fragmentary and truncated particles.

The physical characteristics of these grains seem to be controlled by the method by which the silver bromide is precipitated, on the temperature of precipitation, amount of gelatine present, concentration and presence of additional salts.

FIG. 2.—A.

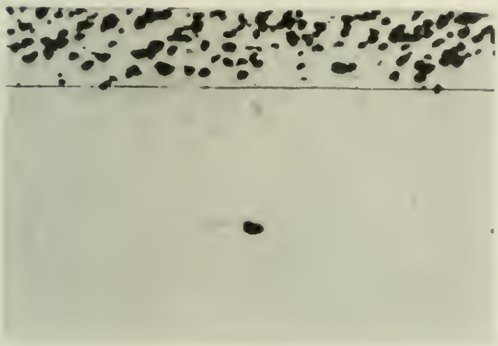
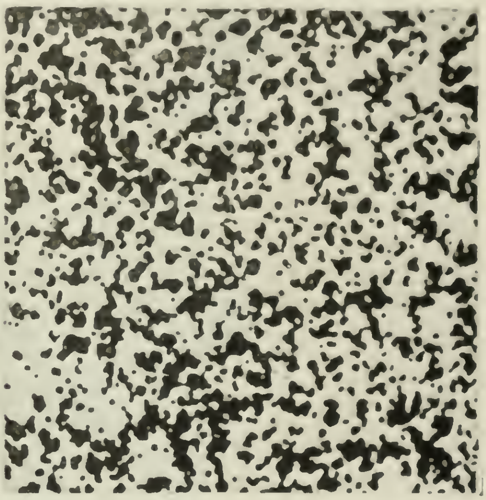


FIG. 2.—B.



"A," vertical section, showing grain-deposit. "B," horizontal plan of grain deposit. Magnification, 375 diameters.

A fairly accurate idea of the size, etc., of these crystals will be gained from the values given in Table I, which gives the physical characteristics of four typical emulsions.

TABLE I.

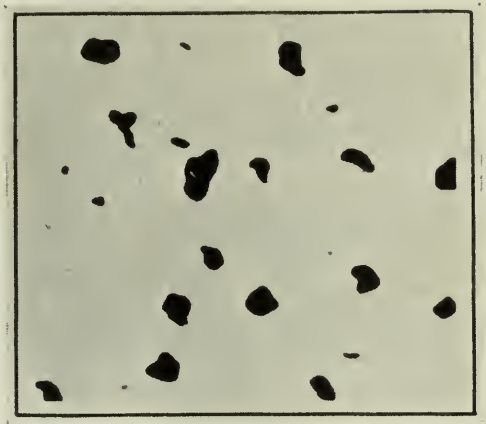
Plate	Average grain size *	Range in grain size †	Shapes
Cine Positive Film..............	1.0μ	0.2 – 2.0μ	Regular, uniform
Seed 23 Plate....................	2.0μ	.2 – 3.5	Regular, uniform
Seed Graflex Plate.............	3.2μ	.2 – 6.0	Irregular, wide variety
Special Experimental Emulsion..	4.0μ	.2 – 8.5	Very regular, variety

* Greatest dimension.
† Resolved.

The fragmentary grains are very numerous in nearly all emulsions. The special experimental emulsion referred to in the above table proved to be very adaptable for the study of individual grain characteristics, its great regularity in shape and freedom from fragments reducing confusion in microscopic examination to a minimum. However, it does not differ greatly, except in this matter of regularity, from the performance of other emulsions, hence the author feels justified in basing certain conclusions on the performance of this emulsion.

The question has often arisen: Are these unexposed grains crystals of pure silver or are they composed of a gelatino-silver complex? From the results of this investigation it seems logical to assume that the inner mass of the grain is pure silver salt, for when water strikes the unexposed crystals no swelling is at all observable, even under the highest power magnification. However, in the majority of cases, when development is complete, the silver deposit is vastly different in form from that of the parent crystal. During development the growing silver mass becomes twisted and distorted. This suggests strong external forces at work, probably due either to an adsorbed layer of gelatine or to almost perfect adhesion to the surrounding gelatine. In the silver bromide crystal, even when water is present in the system, this strain is insufficient to break down the cohesion of the particles of the crystal and distort it, but when the spongy deposit of silver begins

FIG. 3.

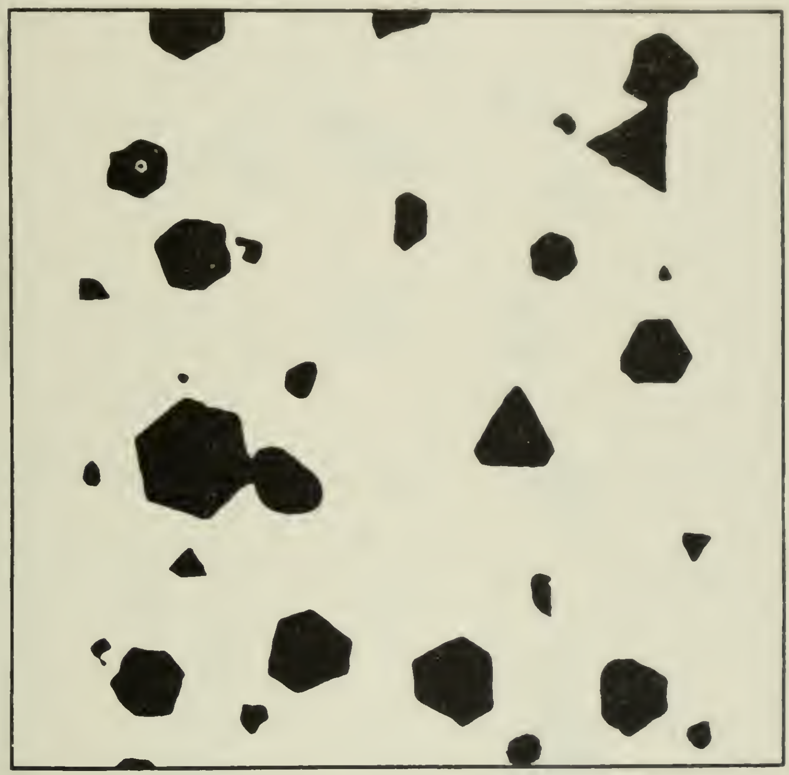


Developed grains. Seed graflex. Magnification, 1350 diameters.

to form, in soot-like particles, the enveloping "bag" of gelatine more or less distorts it.

In the average high-speed plate this distortion is great, causing the developed grains to resemble black popcorn or irregular chunks of coal. In the plate "Special No. 1" this distortion is at a minimum, the developed deposits being almost entirely within the confines of the original crystal. Figs. 3 and 4 illustrate these typical extreme cases. From Fig. 4 we can also gain information as to the geometrical form of the parent crystals.

FIG. 4.



Developed grains. "Spec. No. 1." Magnification, 1350 diameters.

As has been previously stated, these developed grains are masses of fine, sooty black silver, held together by the surrounding gelatine. They may be separated by swelling the gelatine or by applying other mechanical force.

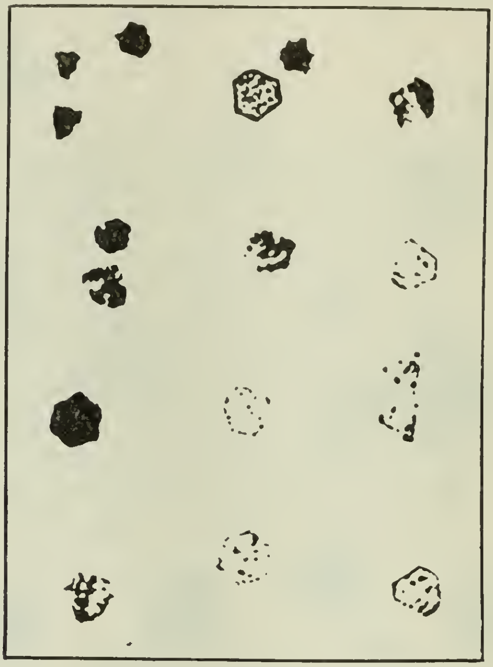
The progress of the development of individual grains has been studied in detail by the following method:

Regularly coated plates were flashed to light, developed slightly, and washed thoroughly to arrest and remove developer.

Some of the emulsion was then removed and examined under high-power magnification. Fig. 5 shows a number of such grains at various stages of development. In most cases development starts at considerably more than one particular point, even in the case of small fragments, and continues (providing time is allowed) until the entire crystal is reduced.

In no case of normal procedure has a curious phenomenon described by Scheffer[1] been observed. Scheffer described and illustrated the development of silver bromide grains under high-power magnification. He showed that in his specimens the grains shot out, or grew, feelers or tentacles during development. These tentacles were subsequently capable of affecting other silver bromide grains, inasmuch as contact seemed to cause developability.

FIG. 5.



Silver bromide grains in various stages of development. Magnification, 1350 diameters.

In only one particular series of enormous overexposures, developed under the arc illumination of the microscope, have any such phenomena been observed by the author. The emulsion in the case in question was coated in a very thin film on the microslide. The primary cause of the shooting out of feelers was here considered to be due to channels or fissures opening up in the gelatine when the developer struck it. In the case of normal thickness of coating (10 to 30 microns) the elastic action is gradual enough in the case of drying after coating and in subsequent swellings to allow time to adjust internal strain. In the case of extremely thin coatings, drying, after the original coating, is far too rapid to permit of equalizing of strain. Such strain regions, in all probability, being greatest in the neighborhood of such "foreign" particles as silver bromide grains, subsequent sudden swelling results in a cleavage at these points. At least the case was special and decidedly abnormal in conditions of

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[1] W. Scheffer, "Microscopical Study of Silver Grains," *British Journal of Photography,* 1907, No. 2441, vol. 54.

FIG. 6.

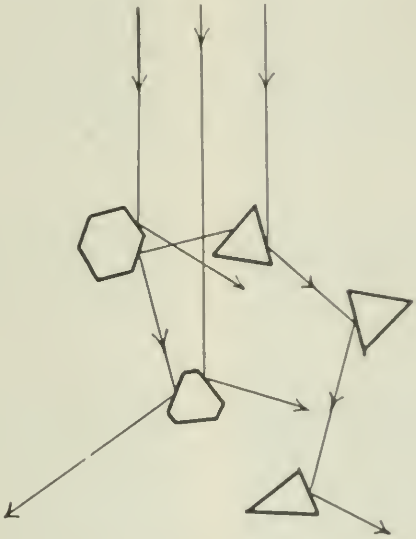
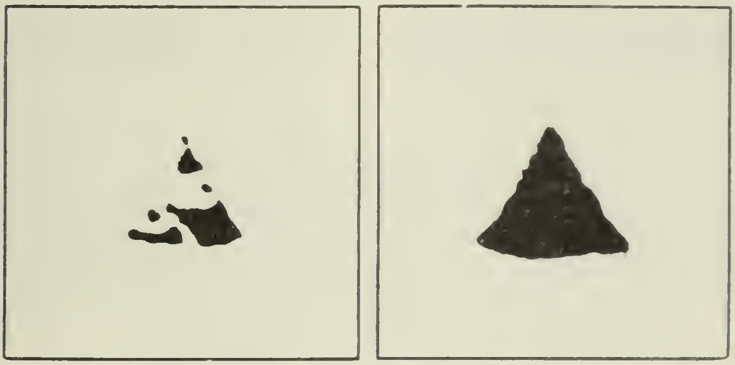


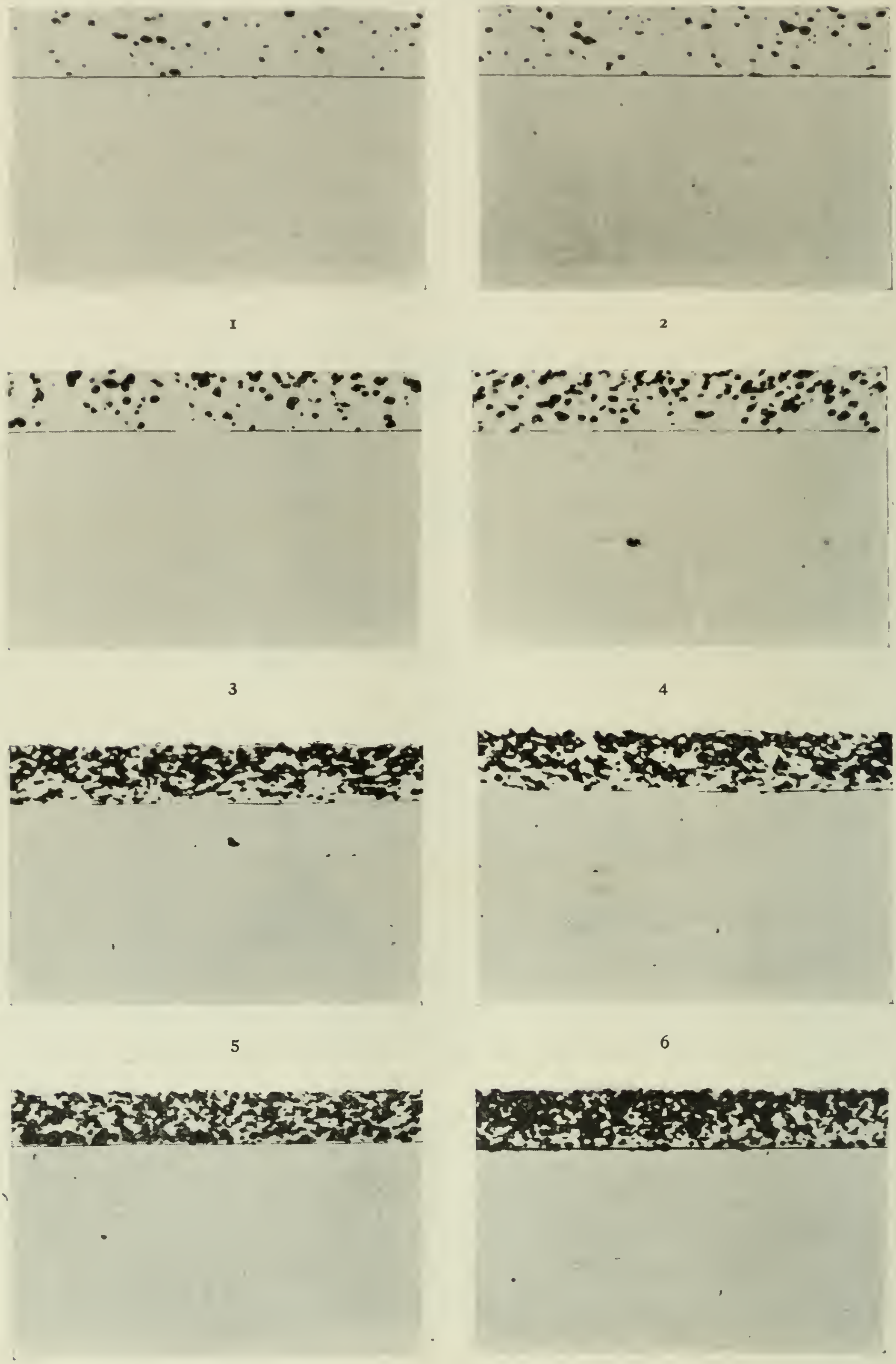
Diagram representing scatter of incident light by silver bromide crystals.

FIG. 7.



Stages of development of single grain. Magnification, 5000 diameters.

FIG. 8.

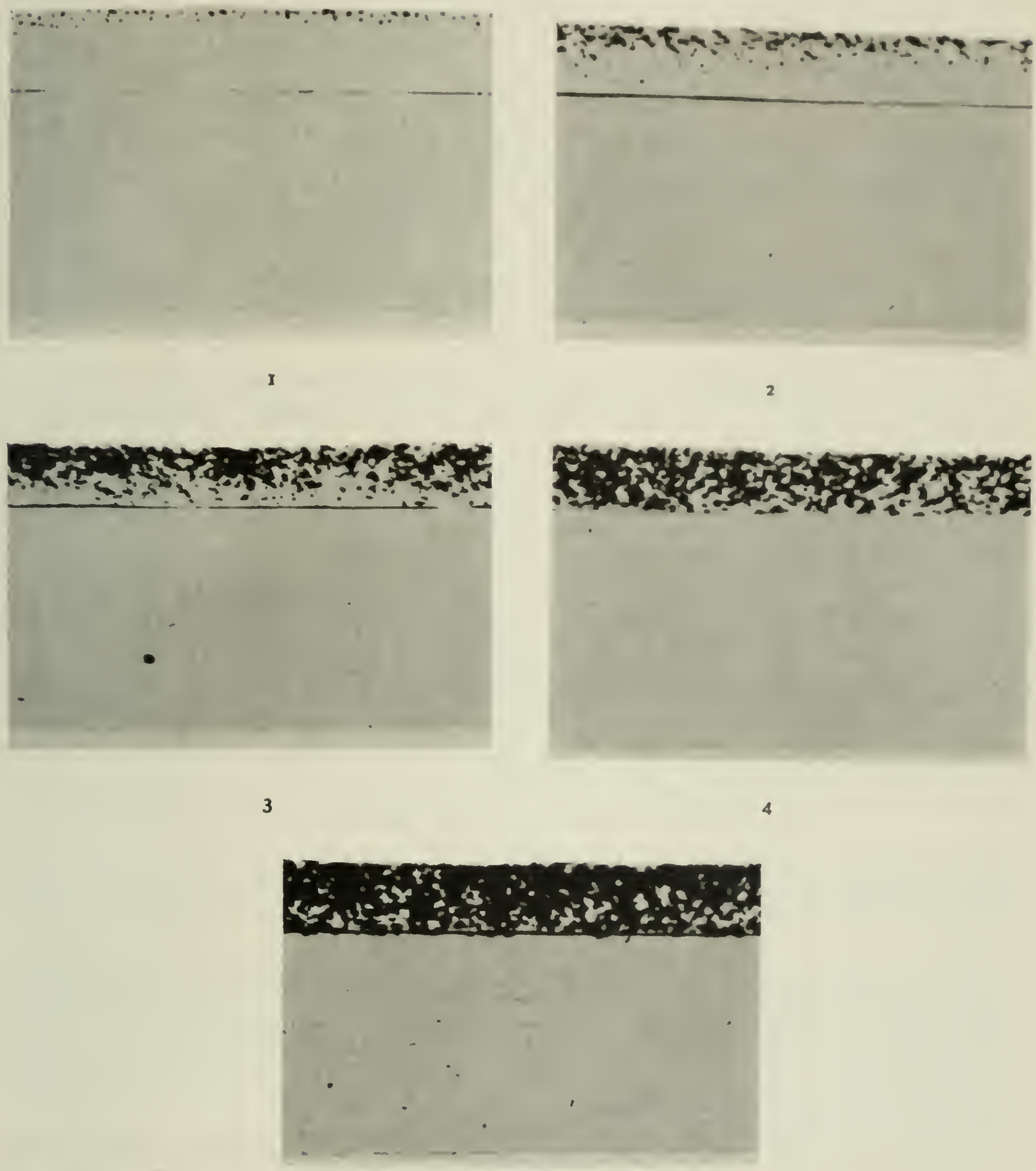


Series of vertical sections (dry), showing growth of image with exposure. Magnification, 375 diameters.

exposure, physical characteristics of the emulsion layer, and development.

In all cases of normal conditions development seems to be a

FIG. 9.



1 2 3 4 5

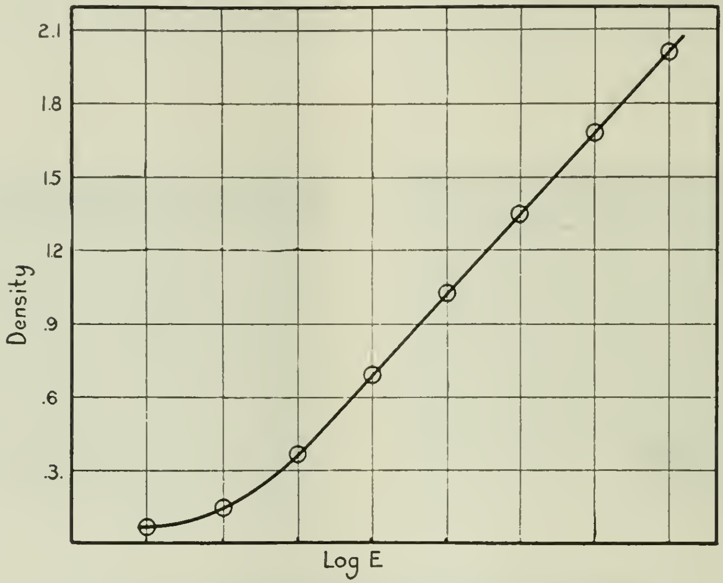
Series showing growth of image with development. Magnification, 375 diameters.

more or less steady transition from silver salt to reduced silver, with the gelatine functioning to cause some distortion of the shape of the individual deposits.

Since the development of a grain starts at a number of points at once, it follows that there must be formed, even in a short exposure, numerous nuclei. This is not to be wondered at when we consider the scatter of light by the emulsion layer (Fig. 6). Probably thousands of molecules or crystal units of each grain are affected by such a seemingly simple exposure.

Two stages of the development of the same grain are shown in Fig. 7. The developed grain in this case is slightly larger than the parent crystal. The ratio of the volume of the crystal to the apparent volume of the developed grain is a function of both inherent characteristics and development. In nearly all cases the developed grain occupied apparently more space than the crystal—"apparently," because the inner mass of the developed grain probably contains gelatine.

FIG. 10.



Hurter and Driffield curve of strip of which sections are shown in Fig. 8. Circles indicate densities of sectioned parts.

No attempt has been made in this investigation to correlate the performance of individual grains with the behavior of the sensitive film as a whole.

The effects of exposure and development and developer on the entire mass, and a study of the resulting "graininess," has not been touched on. However, in the sectioning of dry film to study grain size some interesting photomicrographs were obtained which are shown in Figs. 8 and 9. Fig. 8 shows a section of each step of a Hurter and Driffield test strip whose *D*-log *E* curve is given in Fig. 10. The developer in this case was pyro-soda. The density gradient in each case is somewhat surprisingly shallow.

Fig. 9 shows the developing stages of equal exposures after varying times of development. Many of the fine grains at the lower edge of the image are no doubt parts of large crystals whose development was arrested.

In conclusion I wish to express my indebtedness to Mr. L. A. Jones and Dr. S. E. Sheppard for numerous helpful suggestions given during the course of this investigation.

ROCHESTER, N. Y., September, 1917.

The Elimination of Grade Crossings in Cities. S. T. WAGNER. (*Transactions of the Wagner Free Institute of Science of Philadelphia,* vol. viii, July, 1917.)—A grade crossing is generally understood to mean the crossing of a railroad by a highway when both are at the same level. The same term is applied to the crossing of one railroad by another at the same level. The existence of grade crossings is a necessary evil. When railroads were first constructed in places where the grade crossing is now in existence, there was no other way in which many of these could have been built. At the time the railroads were built, neither the railroads nor the communities which have grown into towns and finally into cities would have been able to bear the expense of construction which would have avoided the crossings at grade, and their existence was therefore an economic necessity.

The history of the work of systematic elimination of grade crossings possibly extends back to about the year 1880, although it did not begin to be considered an important subject until within the past twenty years. During the past fifteen years progress has been steady, and the movement toward the elimination of the most dangerous ones has been rapid on the part of the cities and the railroads. Probably the most extensive work of that kind has been done in the city of Chicago, where, on account of the level character of the ground and the large number of railroads, the conditions are worse than in almost any of the large cities of the United States. It is stated that the elimination of 780 grade crossings had been arranged for in Chicago up to 1911. Philadelphia is credited with the next largest number, namely, 120, and Buffalo third, with 94 to its credit.

In general there are six methods by which a grade crossing can be abolished: (1) Raising the street over the railroad; (2) lowering the street under the railroad; (3) lowering the street and raising the railroad; (4) raising the street and lowering the railroad; (5) raising the railroad over the street; (6) lowering the railroad under the street. In all these cases it is evident that either the street or the railroad must increase its rate of grade, and this single point is generally the most difficult one to deal with in any particular case: the increase in the rate of a grade of a railroad is always accompanied by loss of revenue. On a street it is difficult to calculate actual money loss by increasing the grade. Unfortunately the elimination of such crossings is not profitable to either the city or the railroad from a financial standpoint. Neither can expect to receive any financial return for the large amounts which must be expended.

The Gowlland Multifocal Spectacle Lens. H. O. GOWLLAND. (*Gowlland Optical Company, Limited,* Montreal, Canada.)—Bifocal spectacle lenses for near and distant vision have been known and used since the time of Franklin, and within recent years, particularly since the introduction of "invisible" bifocals, their use has become widespread. Although these lenses obviate the need of two pairs of glasses, the wearer often experiences the discomfort of the "blind zone," or an area within which the distance part of the lens is of too long focus and the near part of too short focus for satisfactory vision. If this blind zone is to be eliminated, a compromise must be made in the powers of the two lenses and the user must be content with less than the maximum possible clearness of vision. A lens of continuously varying curvature within the required limits would evidently provide the necessary conditions for distinct vision at all distances. Such a lens, not having a spherical surface, entails a departure from the usual methods employed in the production of spectacle lenses.

The Multifocal lens embodies this continuous variation of focal length, the difficulties incident to a departure from a truly spherical surface having been successfully overcome. In the manufacture of these lenses the usual system of working has been reversed. The master tool first grinds the curve to a certain degree of fineness, and after that the lens surface itself controls the smoothing and polishing, the surface retaining its ground curve. The finished lens is a clear piece of glass with constantly changing curvature, whose rate of change is governed by the extreme values of the curvature.

While the line of contact between the distance and near parts in the so-called invisible bifocals is quite discernible, the Multifocal lens is free from this characteristic. It is undoubtedly true that the field of view at any given focal value is theoretically limited to points equally distant from the vertex of the curve, but practically, with the relatively small curvatures of spectacle lenses, vision is clear over a considerable zone and an adequate field of view is obtained. The user is thus provided with a lens that responds to the varying requirements of close work and is free from the disconcerting visual jar of an accidental use of the wrong power of the bifocal lens when moving about in an uncertain light.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

THE EFFECT OF VARIOUS PHYSICAL STIMULI ON THE PUPILLARY AREA AND RETINAL SENSIBILITY.[1]

By Prentice Reeves.

[ABSTRACT.]

As there is such a close analogy between the kodak and the eye, an extensive series of investigations is being carried on in physiological optics in this laboratory and this paper gives a brief summary of some of the results obtained up to this time. By making a detailed study of the functions of the eye it is hoped that some information may be discovered relating to some of the new uncertain points in photography.

The eye and the photographic plate are the most widely used instruments for studying light problems, and in practically all cases the final judgments are rendered by the eye. The eye operates through a range of ten billion to one, and maintains a remarkable efficiency throughout a greater part of this extensive range. By knowing the efficiency at which the eye operates we are able to determine the accuracy to which photographic results may be determined.

In this research one of the problems studied was the least amount of physical radiation which will give rise to a perception. This depends on several factors, the greatest of which is the adaptation of the eye. When the eye is fully adapted to absolute darkness its sensibility is the greatest, and the threshold obtained under this condition gives the absolute photochemical reactivity of the retina. When viewing a 1-mm. spot at a distance of 3 metres the minimum radiation visually perceptible was found to be 17×10^{-10} ergs per second. When the test-spot was increased to a 3-cm. square and the observing distance was 35 cm., a dark-adapted eye could just perceive a brightness of

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* Communicated by the Director.

[1] Communication No. 52 from the Research Laboratory of the Eastman Kodak Company, published in *Journal of Ophthalmology, Otology and Laryngology*, September, 1917, and *British Journal of Photography*, 1917, p. 415.

44×10^{-7} millilamberts, while if the eye was adapted to a brightness of the average bright sunny day, the least it could see was about 2 ml. When the size of the test-spot was increased in steps from a 2-mm. square to a 12-cm. square, the results show that the sensibility varies directly as the visual angle up to a value equal to the angle of the fovea and then rises gradually as the peripheral regions are stimulated. By placing an accurately calibrated shutter before the test-spot a series of determinations was made to determine the intensity to which the stimulus should be illuminated to be perceived when exposed for a given period of time.

The distinguishing of detail under all conditions is the fundamental requirement of efficient vision, so the next step was to determine the contrast sensibility of the retina. It was found to increase with an increase in field brightness through the lower intensities, remain constant for the brightness of ordinary vision, and drop off for higher intensities. Throughout ordinary vision the eye is able to detect a difference of 1¾ per cent. in brightness between two adjacent fields. In the determination of glare sensibility it was found that the average eye, when adapted to darkness, could just tolerate a brightness of 25 ml., while if it were adapted to a bright sunny day, the eye could stand a brightness of 16,000 ml. These values give us an idea of what we can see, how well we can see, and what we can comfortably endure.

When the eye is subjected to a change in the brightness of the environment it automatically adjusts itself to the new condition. If the amount of the change is small, the eye adjusts itself practically instantaneously, but if the change is great, an appreciable amount of time elapses. When changing from a given brightness to darkness the eye adapts quite rapidly for the first few minutes and continues to adapt slowly for several hours, although for practical purposes an equilibrium is reached after an hour. When colored light is used we find adaptation is least and most slowly for red, then come yellow, white, green, and blue. When the change is from a low to a higher intensity the change is much more rapid, and a person " gets his eyes " quicker when turning on a light than when turning out a light.

Accompanying the change in sensibility just described is a change in the pupillary diameter, and, while the former varies over a million to one, the latter varies only about 16 to 1. A series of photographs was taken of several subjects over a range of brightnesses from utter darkness to the reflection of direct sunlight from a white paper screen. The average diameter for dark adaptation was 8 mm., the largest diameter for any pupil was 8.6 mm., and the average minimum diameter was 2 mm. The effect of exposing one or both eyes to a given brightness is shown in the following table. The photographs were taken of the right eye in both cases, and the difference between the results in the second and third columns shows the effect of closing the left eye.

TABLE I.

Brightness in millilamberts	Diameter in millimetres Both eyes open	 One eye closed
0.0	7.4	7.5
0.00015	7.15	7.25
0.60	5.3	6.5
6.3	4.1	5.7
126.0	2.6	3.3
2000.0	2.0	2.0

ROCHESTER, N. Y., September 29, 1917.

THE MINIMUM RADIATION VISUALLY PERCEPTIBLE.[2]

By Prentice Reeves.

[ABSTRACT.]

THE previous investigations of the least perceptible radiation have in most cases used stellar light sources and have taken various uncertain values for the area of the pupil. In the present paper the writer used a direct laboratory method, where all physical stimuli were under accurate control and there were no troublesome atmospheric conditions, as in stellar observations. Another advantage was the use of the observers' pupillary measurements obtained from instantaneous flashlight photographs.

To approximate conditions of stellar observations a stimulus one millimetre in diameter was viewed from a distance of three metres. The brightness of the "star" could be varied by the observer and the threshold determined. The observer remained in total darkness for at least fifteen minutes to assure dark adaptation, and used a fixed head rest for constant visual fixation. The results taken under the same conditions from day to day vary through wide ranges and are explained by variations of the pupil, factors of attention and fatigue, ideo-retinal light (caused by retinal circulation), after-images, involuntary eye movements, and the general physiological condition of the observer. As these variable factors are largely beyond experimental control, the only method is to take as many observations as possible over a wide range of time and accept the general average as the threshold value. The writer's threshold value is the average of numerous observations, and results were also obtained from two other observers and averaged with the writer's values for those days.

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[2] Communication No. 51 from the Research Laboratory of the Eastman Kodak Company, published in *Astrophys. Jour.*, September, 1917, p. 167.

If we let B = normal candle-power per square centimetre of source, and assuming the inverse square law and a point source, the flux through 1 square centimetre on the axis at the eye will be

$$SB/R^2 \text{ lumens}$$

and the flux through the pupil of area A will be

$$F_p = SBA/R^2 \text{ lumens.}$$

Now $$B = \text{Lumen}/\pi \text{ and } A = \pi r^2$$
so $$F_p = SL\ r^2/R^2$$

where F_p is the flux through the pupil, S the area of the star, L the star brightness in lamberts, r the radius of the pupil; R is the distance of the eye from the star. If the equation is then multiplied by the mechanical equivalent of light, M, we get

$$\text{Least perceptible radiation} = SLM\ r^2/R \text{ ergs per second.}$$

Using the 1-mm. star at a distance of 3 metres, the writer's values for L and r were 0.0072 millilambert and 4.65 mm., which gives a result of 17.1×10^{-10} ergs per second. The average result for three observers was $L = 0.0088$ ml., $r = 4$ mm., and least perceptible radiation = 19.5×10^{-10} ergs per second.

NOTES FROM THE RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY.*

THE CONSTITUTION AND FUNDAMENTAL PROPERTIES OF SOLIDS AND LIQUIDS. PART II.—LIQUIDS.[1]

By Irving Langmuir.

THIS paper extends the application of the viewpoint of Part I—Solids (*Journal of the American Chemical Society*, 38, 2221–95, November, 1916)—to a consideration of the structure of liquids.

An extended discussion of the phenomena and forces involved in the spreading of oil films upon water is followed by the following general conclusions:

"*A.* Forces of the type which Gurvich has called physical forces do not play any important part in the structure of matter. The best examples of the physical forces are gravitation and the forces between electrically charged bodies. Gravitation is much too small a force to be of influence in holding atoms and molecules together. In all ordinary matter the negative and positive electricity are so uniformly distributed throughout the mass that the effective range of these electric forces is only of atomic dimensions.

"*B. All* the interatomic and intermolecular forces involved in the structure of matter are chemical forces; that is, they are of the same nature as the forces that the chemist has been studying in the past. In general, these forces are of two kinds: those represented by primary and those represented by secondary valence."

Needed Improvement in Primary Batteries. ANON. (*Electrical World*, vol. 70, No. 15, p. 703, October 13, 1917.)—The really serious need of improvements in primary batteries has been repeatedly suggested. This need is just now sharply emphasized by the very wide use of electric flashlamps in the trenches. A flashlamp is practically indispensable as part of the equipment of all officers and of all men who have to share in the cave life of the western front. The advent of the tungsten lamp has given a very practicable source of light which does not make severe demands for current and is altogether successful for the purpose intended. But who shall say that the ideal battery for such service has yet made its appearance? The battery now almost universally used is of an old familiar type, somewhat improved in detail and really a wonderfully good article for its price, but it is essentially a battery strictly for temporary use and deteriorating on open circuit. The resources of the chemical engineer ought to be able to give us a source of electricity combining compactness, comparative freedom from polarization, and reliability. Of course, the cheaper the better, other things being equal, but it need not attempt to compete with the common type in the mere matter of first cost. Of chief importance is that it should hold up its voltage well and be free from serious deterioration when not in use. Surely the resources of invention at the present time ought to give us a battery much more suitable for hard service than the Leclanché type of cell, which has heretofore had the field practically to itself. Nothing has been able to compete with this old-timer for general use, but its limitations are such as to point the need for a successor. The thanks of the men in the trenches and no small monetary reward are likely to come to him who first produces the battery required.

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* Communicated by the Director.

[1] *Journal of the American Chemical Society*, 39, 1848–1906, September, 1917.

Steel Reinforcing in Wooden Ships. ANON. (*Iron Trade Review,* vol. lxi, No. 13, p. 658, September 27, 1917.)—In addition to the immense steel shipbuilding program of the reorganized shipping board, over 300 seagoing wooden vessels of various types are under construction in American yards. Even these vessels, however, must pay their tribute to the iron and steel industry. It is estimated that about 60,000 tons of steel will be required for the wooden vessels now on the ways or under contract. Most of the steel will be used for fastenings, including spikes, drift bolts, through bolts, nuts, washers, clinch rings, etc.

In order to provide the necessary strength, large wooden vessels must be reinforced with steel straps. Universal plates 14 inches wide and ¾ inch thick are sometimes used. The arch rises amidships to a point 3 feet above the main deck. At both ends the straps run down to the line of the bilge. In addition, the deck beams are tied together by ¾ × 4-inch steel straps laid in four courses the full length of the ship. This strapping is rather expensive, the type used costing about $3000, including $1500 for labor and fastenings. This form of reinforcing, however, is not nearly so elaborate as that provided in the standard design of the United States Shipping Emergency Fleet Corporation. This design provides for a lattice work of steel straps, ½ × 4 inches, connected to a ¾ × 8-inch steel cord at the top. It costs about $8000 to reinforce a ship.

Cast-steel knees are extensively used by wood-ship builders on the Pacific coast. These knees are about 4 feet on a side, the metal being approximately ¾ inch thick. They are placed under the ends of deck beams, thus adding to the rigidity of the hull structure. The steel foundries on the Pacific coast have built up an attractive business manufacturing these knees.

NOTES FROM RESEARCH DIVISION, ELECTRICAL ENGINEERING DEPARTMENT, MASSACHUSETTS INSTITUTE OF TECHNOLOGY.*

SOME EXPERIMENTS ON THE EFFECTS OF CHANGES IN DIAPHRAGM THICKNESS ON THE CHARACTERISTICS OF A TELEPHONE RECEIVER.

It was shown by Lord Rayleigh [1] that the natural frequency of a circular plate diaphragm, such as is used in a telephone receiver, is directly proportional to the thickness and inversely proportional to the area of the plate. This is on the assumption that the material of the plate remains uniform and homogeneous, and that all other conditions remain constant.

Some experiments were made in the Electrical Engineering Department of the Massachusetts Institute of Technology and Harvard University, by Mr. C. H. Calder, in a graduating thesis, during 1915, on the effect of changing the thickness of the telephone diaphragm on the characteristics of the instrument. The results obtained are here summarized.

The telephone receiver used was a regular bipolar instrument of a standard make. It had a resistance of about one hundred ohms at 20° C. The inner diameter of the clamping circle was 5 cm. The tests were made by obtaining the motional-impedance circle of the instrument over a range of impressed frequency from 400 to 1500 cycles per second, as furnished by a Vreeland oscillator. The different diaphragms were of standard ferrotype steel, one japanned and one unjapanned of each successive thickness. They were all of the same diameter, and they varied in metallic thickness from 0.14 mm. to 0.325 mm. (5.5 to 12.8 mils) in five steps. The results obtained with the japanned and unjapanned diaphragms of the same metallic thickness differed slightly, but not in any recognized systematic way, so that, in what follows, the mean of the two results for each thickness has been taken. The same receiver and cap were used throughout, and the cap was screwed on with substantially the same measured torque before each test.

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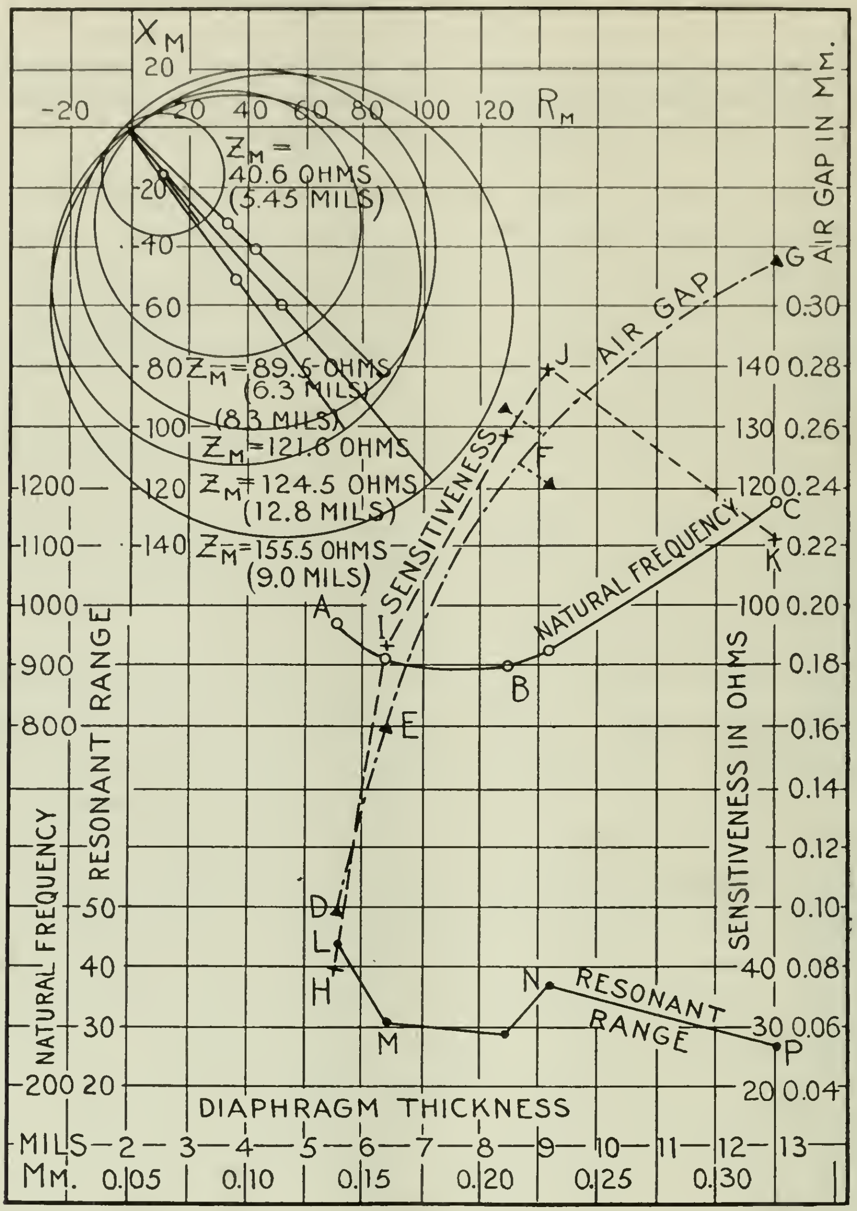
* Communicated by the Director.

[1] "Theory of Sound," 2d Ed., vol. 1, p. 367 (1894).

The results are summarized graphically in the accompanying figure. It will be seen that as the metallic thickness of the diaphragm was increased from 0.13 to 0.33 mm. the resonant or natural frequency followed the curve *ABC* from *A* at 970 ∾



to *C* at 1175 ∾. If the frequency had been proportional to the thickness, the graph would have been a straight line from the origin to some point such as *C*.

A reason for the departure from the simple straight-line law is found in the air-gap curve *DEFG*, which varies from 0.1 mm.

with the thinnest diaphragm to nearly 0.32 mm. with the thickest. These air-gaps were measured by means of a depth gauge, after the diaphragms were set in place. It is evident that the thin diaphragms are bowed in toward the centre by the magnetic attraction of the permanent poles. This inward bending not only distorts the diaphragm, but it also tends to make it behave partly like a stretched membrane rather than like a simple plate. The laws of vibration of a membrane and of a plate are different. The curve *ABC* indicates, however, a tendency to follow a simple straight-line law from the origin, toward the thicker diaphragms, which suffer the least bending and have the largest air-gaps.

Graph *HIJK* shows the " sensitiveness " of the receiver with the various successive diaphragms, as deduced from the diameters of the mean corresponding motional-impedance circles. These circles are reproduced in the left-hand top corner of the figure, for the japanned diaphragms only. It is known that for one and the same telephone receiver, operated at constant alternating-current strength, the sensitiveness of the apparatus is proportional to the diameter of the motional-impedance circle. It will be seen that the graph indicates a maximum of 140 ohms, near to 0.13 mm. thickness. This property depends both on the mechanics of the diaphragm and on the electromagnetics of the instrument, as influenced by the air-gap, so that the relation to diaphragm thickness is not a simple one.

Finally, the broken line *LMNP* represents the successive observed " resonant ranges " of the instrument, in cycles per second, as taken from the mean motional circles. The resonant range may be defined as the difference between the two frequencies—one on each side of the resonant frequency—at which the kinetic energy of vibration under constant alternating-current excitation falls to one-half. It may be found from the difference of the quadrantal point frequencies in the circle. Sharp resonance means a small range, and blunt resonance a large range. Theoretically, the resonant range of a simple plate diaphragm should vary inversely as the thickness: [2] so that doubling the thickness should halve the range. The graph suggests a rough approximation only to this simple theoretical relation.

It may be observed, as a matter of interest, that the depression angles of the diameters of the various motional-impedance circles remain not far from 45 degrees throughout the series.

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[2] " Motional-Impedance Circle of the Telephone Receiver," by H. O. Taylor, *Proc. Radio Club of America*, June, 1917.

Conclusions.—The observations indicate that the natural frequency of a telephone receiver is not simply proportional to the diaphragm thickness—for at least one reason: that the thin diaphragms are subject to greater magnetic distortion. The observed sensitiveness passed through a maximum for this particular instrument near to the thickness of 0.23 mm. The resonant range diminished as the thickness increased.

More than fifty motional-impedance circles were measured and computed in the course of the research.

We are indebted to the Western Electric Company for the various samples of diaphragm which were used in the test, and also to Mr. H. A. Affel for his assistance and suggestions.

Packing and Plant Handling of Hazardous Chemicals. N. A. LAURY. (*Metallurgical and Chemical Engineering*, vol. xvii, No. 7, p. 407, October 1, 1917.)—Many attempts have been made to devise a safe and economical package for the transport of the convenient quantity of one or two hundred pounds of acid or other corrosive liquid, but nothing has yet been suggested that equals the standard form of wood-packed glass carboy for general use. The greatest danger in the handling of carboys is the sudden giving away of the bottom or sides of the box, due to the corrosion of the nails or weakening of the wood by acid, especially after long storage. This danger can be satisfactorily eliminated by the use of wood preservative. Untreated boxes last about two years under normal conditions. During this period the box has to be renailed three times and requires one new bottom and one new cover. Carboys treated two years ago are still in service, and very few of them have required renailing and none have had new covers or bottoms. This applies also to the standard lead carboy for the transport of hydrofluoric acid. Steel drums are used for this purpose in Europe and are said to be safer and cheaper, but they are not yet accepted for rail shipments in this country.

There is in current use a stoneware stopper and plaster-of-paris, tied down with cloth, the latter sometimes coated with tar or paraffin. If the plaster is mixed in small quantities and applied fresh, it holds so firmly that the carboy may be moved about by the stopper, but in a few days the acid loosens the grip of the plaster, and the cloth, even when treated, crumbles away. The safest stopper in use consists of a glass or stoneware plate with a tar paper, asbestos, or rubber jacket held on by a wire clip like a fruit jar.

THE FRANKLIN INSTITUTE

(*Proceedings of the Stated Meeting held Wednesday, October 17, 1917.*)

Hall of The Franklin Institute,
Philadelphia, October 17, 1917.

President Dr. Walton Clark *in the Chair.*

In calling the meeting to order the Chairman announced that a number of changes, which are expected to be only temporary, had occurred in the Institute management, due to the present war. Dr. Owens, the secretary, is now with the American Expeditionary Forces in France as a major in the Signal Corps. Mr. T. R. Parrish, Science and Arts Assistant, is now lieutenant in the Signal Corps. Mr. William C. Wetherill, chairman of the Committee on Science and the Arts, and member of the Board of Managers, is at present located in Boston, Mass., in the Naval Aviation Department of the Massachusetts Institute of Technology, where he will receive his commission as lieutenant, and Mr. Theobald F. Clark, member of the Board of Managers, is now a captain in the Artillery. The Chairman further stated that Dr. George A. Hoadley is serving as Acting Secretary during the absence of Dr. Owens.

Additions to membership since last report, 13.

Mr. Louis E. Levy, chairman *pro tem.* of the Committee on Science and the Arts, reported the conditions of the work of the committee.

The President announced that the first business of the meeting would be the presentation of the Edward Longstreth Medal of Merit on recommendation of the Committee on Science and the Arts, and recognized Mr. Louis E. Levy, who, on behalf of the Committee on Science and the Arts, introduced Mr. P. Noyes Riedinger, the representative of the Hooven, Owens, Rentschler Company, of Hamilton, Ohio, who had been recommended for this award for "the development of ingenious methods used in the manufacture of the Hooven Automatic Typewriter."

The President presented the medal and accompanying certificate to Mr. Riedinger, who expressed his thanks for the distinction conferred upon his company.

The paper of the evening was then presented by Gellert Alleman, Ph.D., Professor of Chemistry, Swarthmore College, Swarthmore, Pa., entitled "Occluded Gases in Ferrous Alloys." The speaker presented a comprehensive review of previous researches and investigations on occluded gases, including the work of Graham, Bessemer, Parry, Stead, Weaver, Richards, Pursell, Brown, Boudouard, and others, with a description of some of the apparatus used by the various investigators. The lecturer then described in detail a new apparatus which he devised and has employed in his experiments. The changes in physical and chemical properties of ferrous alloys due to the presence or absence of gases were fully described. The lecture was illustrated by high-temperature and vacuum apparatus and numerous lantern slides. In the discussion which followed the reading of the paper, Mr. Levy, Doctors Northrup and Hering, and others participated.

A vote of thanks was extended to the speaker, and the meeting then adjourned.

GEORGE A. HOADLEY,
Acting Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of the Stated Meeting held Wednesday, October 3, 1917.*)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, October 3, 1917.

MR. LOUIS E. LEVY, *Chairman pro tem.*

The following report was presented for reconsideration and adopted:

No. 2668.—Linear Hot-Wire Anemometer. Recommended that Howard N. Potts Medals be awarded to Dr. A. E. Kennelly, for his invention of the Hot-wire Anemometer, and to Prof. Louis Vessot King, for his improved method and researches in Hot-Wire Anemometry.

The following report was presented for Final Action:

No. 2702.—Austin Organ. Recommended that the Edward Longstreth Medal of Merit be awarded to John T. Austin, of Hartford, Conn., for his invention of the "Universal Wind Chest," and its practical application in the Austin Organ.

GEO. A. HOADLEY.
Acting Secretary.

SECTIONS.

Mechanical and Engineering Section.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, October 4, 1917, at 8 o'clock, with Dr. George F. Stradling in the chair. The paper of the evening, entitled "The American Air Service," was presented by Dr. W. F. Durand, Chairman, National Advisory Committee for Aeronautics, National Research Council.

The lecturer reviewed the various steps taken in the development of the great air fleet for military use in France, and referred briefly to the equipment of the different types of machines, their chief characteristics and requirements for effective service. The development of the United States aeronuatic engine was described, with same intimation of the steps taken for its production in large quantity. The special needs of the naval aeronautic service were also discussed. The training of military aviators through the various stages was considered, and a description was given of the manner in which such training is now being carried out at the various training camps in the United States.

The instrumental and military equipment of a modern airplane was described, including the instruments required for navigation, the machine-guns, bombs, and bomb-dropping devices. The subject was illustrated by a large collection of lantern slides.

After a brief discussion a vote of thanks was extended to the speaker and the meeting adjourned.

GEORGE A. HOADLEY,
Acting Secretary.

Electrical Section.—A joint meeting of the Section and the Philadelphia Section, American Institute of Electrical Engineers, was held in the Hall of the Institute on Thursday evening, October 11, 1917, at 8 o'clock. Mr. W. C. L. Eglin and Mr. Nathan Hayward presided jointly.

A communication, entitled the "Propulsion of Ships," was presented by Mr. Eskil Berg, of the General Electric Company, Schenectady, N. Y.

The speaker reviewed briefly the present methods for propelling vessels, devoting considerable attention to the steam turbine as applied to marine propulsion. Geared turbines and electric drive installations were also considered, and the economical and efficient results obtained from such installations were pointed out.

The electric propelling machinery installed in some of the more recent warships was described in detail. The subject was fully illustrated by lantern slides.

After a discussion by several members and visitors the thanks of the meeting were extended to the speaker.

Adjourned.

GEORGE A. HOADLEY,
Acting Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, October 10, 1917.*)

RESIDENT.

MR. CHARLES HART, President, Delaware River Steel Company, Chester, Pa.

MR. WILLIAM F. TURNBULL, Instructor, University of Pennsylvania, Philadelphia, Pa.

NON-RESIDENT.

MR. WILLIAM H. BASSETT, Technical Superintendent, American Brass Company, Waterbury, and for mail, Cheshire, Conn.

MR. JOSEPH J. WILLIAMS, Mechanical Draftsman, Wadesville, Ind.

CHANGES OF ADDRESS.

MR. PHILIP WERNER AMRAM, 4000 Pine Street, Philadelphia, Pa.

MAJOR JOHN H. BARR, St. Nicholas Apartments, 2230 California Street, Washington, D. C.

MR. G. E. CHAMBERLAIN, 2044 Maplewood Avenue, Toledo, Ohio.

MR. FRANCIS T. CHAMBERS, 605–608 New Stock Exchange Building, 1411 Walnut Street, Philadelphia, Pa.
MR. HAROLD V. COES, 42 Forest Street, Monclair, N. J.
MR. SAMUEL H. COLLOM, 505 Abbott Building, Philadelphia, Pa.
MR. A. DE MACEDO, 5340 Magnolia Avenue, Germantown, Philadelphia, Pa.
MR. LOUIS A. FERGUSON, 1601 Wesley Avenue, Evanston, Ill.
MR. ELMER K. HILES, 568 Union Arcade Building, Pittsburgh, Pa.
MR. J. ROGERS HOLCOMB, Walnut Hill, New Castle, Del.
MR. ZAY JEFFRIES, care of Aluminum Castings Company, 2800 Harvard Avenue, Cleveland, Ohio.
MR. E. E. KELLER, 621–659 Bellevue Avenue, Detroit, Mich.
LIEUT. CHESTER LICHTENBERG, Company 2, E. R. O. T. C., Camp American University, Washington, D. C.
MR. R. L. O'DONNEL, Pennsylvania Railroad Company, 309 Broad Street Station, Philadelphia, Pa.
MR. ROBERT S. REDFIELD, Wayne, Pa.
MR. W. S. RUGG, The University Club, 4439 Grant Boulevard, Pittsburgh, Pa.
MR. I. F. STONE, 244 Madison Avenue, New York City, N. Y.
DR. L. M. TOLMAN, 6505 Harvard Avenue, Chicago, Ill.
MR. LOUIS B. WHITNEY, Alpha Portland Cement Company, 428 Oliver Building, Pittsburgh, Pa.
MR. J. D. WILLIAMSON, 69th Avenue and 11th Street, Oak Lane, Philadelphia, Pa.

NECROLOGY.

Virgil G. Bogue was born at Norfolk, N. Y., July 20, 1846, and died at sea on October 14, 1917.

His early education was obtained in his native town and at Russell's Military School, New Haven, Conn. He graduated from the Rensselaer Polytechnic Institute as a Civil Engineer in 1868. Mr. Bogue began his professional career, which covers nearly fifty years, as assistant engineer of Prospect Park, Brooklyn. From 1869 to 1879 he was assistant engineer of the Oroya Railway and manager of the Trajille Railway in Peru. He then became assistant engineer of the Northern Pacific Railway Company, and for several years supervised the construction of the railroad across the states of Idaho and Washington. In 1886 he was appointed chief engineer of the Union Pacific Railroad, and five years later opened consulting engineering offices in New York City.

Mr. Bogue was a member of the commission appointed by President Harrison to investigate the methods for improving navigaton of the Columbia River. He was consulting engineer for the Government of New Zealand, and acted in the same capacity for the Department of Public Works of New York and the Western Maryland Railroad.

From 1905 to 1909 he was chief engineer and vice-president of the Western Pacific Railway. He prepared plans for the improvement of the city of Seattle, Washington; for the Harbor of Tacoma, and for Gray's Harbor, Washington.

He was a member of numerous engineering societies and clubs. He became a member of The Franklin Institute on June 11, 1914.

Amos Peaslee Brown was born in Germantown, Philadelphia, on December 3, 1864, and died at Atlantic City, N. J., on October 9, 1917. After a general educational training he entered the University of Pennsylvania in 1882 and was graduated as a Mechanical Engineer.

From 1887 to 1889 he served as an aide on the Second Geological Survey of Pennsylvania, and in the latter year joined the staff of the University of Pennsylvania as instructor in mining and metallurgy. He received the degree of Doctor of Philosophy from the University in 1892, and was appointed professor in mineralogy and geology, which position he held until May, 1917, when he resigned on account of ill-health.

Dr. Brown was the author of numerous papers on geology, mineralogy, and palæontology, and in 1901 edited "Erni's Mineralogy." He is the author, with E. T. Reichert, of the work on "Crystallography of Hæmoglobin," in two volumes, published in 1909.

Doctor Brown was a member of the leading scientific societies of this country. He became a member of The Franklin Institute on April 25, 1890.

William Horstmann was born in 1855 and died on October 11, 1917. When a young man he was employed for a short time by the William H. Horstmann Company, the firm founded by his grandfather. He spent most of his time in recent years in travelling.

Mr. Horstmann was a member of numerous clubs and societies. He became a member of The Franklin Institute on May 14, 1881.

Edward deVeaux Morrell was born at Newport, R. I., on August 7, 1862, and died at Philadelphia on September 1, 1917.

He was graduated from the University of Pennsylvania with high honors in 1885, and the degrees of Master of Arts and Bachelor of Laws were conferred upon him in the year 1887, in which year he was also admitted to the bar.

In 1891 he was elected a member of Select Council of Philadelphia, serving for three years. He entered the National Guard of Pennsylvania as colonel of the Third Regiment, was promoted to inspector general, and later became brigadier general, commanding the First Brigade. He was elected a member of the Fifty-sixth Congress in 1900, and was three times re-elected, serving until 1907.

General Morrell became a member of The Franklin Institute on December 10, 1907.

George Smith Rider was born at Providence, R. I., on May 4, 1858, and died suddenly at Cleveland, Ohio, on September 11, 1917.

His early education, as well as his collegiate training, was received in New England, where he also began his engineering career as apprentice with the Brown & Sharpe Manufacturing Company. After a few years of travel abroad he located at Cleveland, Ohio, and obtained a position with the Warner & Swazey Company. He next became connected with the Cummer Engine Company, where he remained until he was appointed an instructor at the University School of Cleveland.

While connected with the University School he opened a consulting engineering office, which he conducted successfully for a period of about fifteen years. Mr. Rider devoted his attention to the designing of power and industrial plants.

He was a member of the leading engineering societies, and his membership in The Franklin Institute dates from January 31, 1901.

Mr. Charles A. Catlin, 133 Hope Street, Providence, R. I.
Mr. Llewelyn T. McKee, 318 East Market Street, Bethlehem, Pa.

LIBRARY NOTES.

PURCHASES.

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Moody's Manual of Railroad and Corporation Securities, vol. 18, 3 parts. 1917.
National Association of Cement Users, Proceedings No. 13. 1917.
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United States Department of Agriculture, Year Book. 1915.

GIFTS.

Alberger Pump and Condenser Company, Catalogues E and No. 7, and Bulletins Nos. 16, 17, 20, 21, and 22. New York, 1907–1916. (From the Company.)
Allis-Chalmers Manufacturing Company, Catalogue No. 1632-A, Centrifugal Pumps and Pumping Units. Milwaukee, Wis., 1915. (From the Company.)
American Bridge Company, Standards for Detailing. Ambridge, Pa., 1911. (From the Company.)
American Cement Tile Manufacturing Company, Bonanza Cement Tile Roofing and Data Sheets, Second Edition, Pittsburgh, Pa., 1914, 1917. (From the Company).
American Institute of Metals, Transactions, vol. x, 1916. Buffalo, N. Y., 1917. (From the Institute.)
American Steel Export Company, Steel and Metals Department Catalogue. New York, 1917. (From the Company.)
American Valve and Meter Company, Catalogue, The Anderson Economy Switch Stand. Cincinnati, no date. (From the Company.)

Atlas Portland Cement Company, Concrete in Railroad Construction; Concrete on the Farm, and Reinforced Concrete in Factory Construction. New York, 1915–1917. (From the Company.)

Blaw Steel Construction Company, Bulletins Nos. 66, 67, and 69. Pittsburgh, Pa., 1915. (From the Company.)

Bowser, S. F., & Company, Inc., Bulletins of Oil Tanks, Pumps, and Storage Systems. Fort Waye, Ind., 1917. (From the Company.)

Bridgeport Brass Company, Bulletin No. 10, Phono Electric Trolley Wire. Bridgeport, Conn., 1917. (From the Company.)

British Columbia Department of Lands, Water Rights Branch, Report for the Year Ending December 31, 1916. Victoria, 1917. (From the Department.)

Buffalo Department of Public Works, Twenty-third Annual Report, July 1, 1914–June 30, 1915. Buffalo, N. Y., 1915. (From the Department.)

Buffalo Meter Company, Catalogue of American and New Niagara Water Meters. Buffalo, N. Y., 1916. (From the Company.)

Builders Iron Foundry, Bulletins Nos. 84, 86, and 90. Providence, R. I., no dates. (From the Foundry.)

Cameron, A. S., Steam Pump Works, Bulletins Nos. 151, 152, 7055, 7104, 7150, and 7251. New York, 1914–1917. (From the Works.)

Carborundum Company, Catalogue No. 6, Carborundum and Aloxite Wheels for all Classes of Grinding. Niagara Falls, N. Y., 1917. (From the Company.)

Defender Automatic Regulator Company, Bulletins G, J, K, L, M, N, O, and R. St. Louis, Mo., 1917. (From the Company.)

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Federal Trade Commission, Report on Anthracite and Bituminous Coal, June 20, 1917. Washington, 1917. (From the Commission.)

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Haverhill, Mass., Engineering Department, Annual Report of the City Engineer for the Year ending December 31, 1916. Haverhill, 1917. (From the Department.)

Hayward Company, Catalogue No. 43, Hayward Buckets. New York, 1916. (From the Company.)

Hoevel Manufacturing Corporation, Catalogue F, of Sand Blast Machines. New York, 1917. (From the Corporation.)

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Western Australia Water Supply, Sewerage, and Drainage Department, Fourth Annual Report, 1915–1916. Perth, 1916. (From the Department.)

Western Electric Company, Electrical Supply Year Book, 1918. New York. 1918. (From the Company.)

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Worthington Pump and Machinery Corporation, Bulletins, BK-877, 880, 881, 889, 1000B, 1600; C-211b; D-400, 700, 800, 900; L-530A, L-533; P-35A; W-177, 185-B, 204, 308, 600, 601, and 602. New York, 1910–1917. (From the Company.)

BOOK NOTICES.

Practical Structural Design, by Ernest McCullough, C. E. New York, U. P. C. Book Company, 1917. 303 pages, illustrations, 6 × 9 inches, cloth. Price, $2.50.

In the field of structural design, particularly as applied to building construction, the procedure in fixing the sizes of the component members of a structure have been reduced, relatively speaking, to a few simple theorems of statics not difficult to comprehend and apply with a limited mathematical equipment; and, with the protection of carefully drawn building laws, no very serious mistakes can be made on occasional problems of design which might strictly require an analysis beyond the powers of those whose acquaintance with the subject is thus limited.

The book is primarily intended for this class of readers—men who cannot attend evening classes. It is also intended as a text-book in such classes. The subject-matter consists of the usual problems of practice, which really constitute all but a small percentage of design operations. Being limited as to mathematical treatment, some important theorems have to be stated without formal proof. The work is divided under the following general headings: External Forces, 47 pages; Internal Forces, 29 pages; Problems in Design of Beams, 17 pages; Girders and Trusses, 34 pages; Joints and Connections, 71 pages; Graphic Statics, 34 pages; Columns and Struts, 54 pages; Index, 8 pages.

The work is very practical as well as deductive in treatment and is well adapted to the needs of evening-school students.

Lucien E. Picolet.

PUBLICATIONS RECEIVED.

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Los Angeles City Club: Report on Government Ownership of Public Utility Service Undertakings. Prepared by the Committee on Municipal Ownership. 38 pages, diagram, 8vo. Los Angeles, City Club, 1917.

Iowa Agricultural Experiment Station: Bulletin No. 172, Managing a Tuberculous Herd. 12 pages, illustrations. Circular No. 38, Soft Cheese Making, by R. W. Brown and M. Mortensen. 4 pages. Circular No. 39, Hay and Pasture Seedings. 12 pages, illustrations. 3 pamphlets, 8vo. Ames, Iowa, Station, 1917.

University of Illinois Bulletin: The Effect of Mouthpieces on the Flow of Water Through a Submerged Short Pipe, by Fred B. Seely. Bulletin No. 96, Engineering Experiment Stations. 53 pages, illustrations, 8vo. Urbana, Illinois, 1917. Price, 25 cents.

Practical Structural Design: A text and reference work for Engineers, architects, builders, draftsmen, and technical schools; especially adapted to the needs of self-tutored men, by Ernest McCullough, C. E., Member American Society of Civil Engineers. 303 pages, illustrations, 8vo. New York, U. P. C. Book Company, 1917.

U. S. Bureau of Mines: Bulletin 120, Extraction of Gasoline from Natural Gas by Absorption Methods, by George A. Burrell, P. M. Biddison, and G. G. Oberfell. 71 pages, illustrations, plates. Bulletin 138, Coking of Illinois Coals, by F. K. Ovitz. 71 pages, illustrations, plates. Bulletin 152, Abstracts of Current Decisions on Mines and Mining, reported from January to April, 1917, by J. W. Thompson. 78 pages. Technical Paper 167, Men Who Received Bureau of Mines Certificates of Mine-rescue Training, July 1, 1914, to June 30, 1916, compiled by D. J. Parker. 66 pages. Technical Paper 175, Production of Explosives in the United States During the Calendar Year 1916, with Notes on Coal-mine Accidents Due to Explosives and List of Permissible Explosives, Lamps and Motors Tested Prior to March 31, 1917, compiled by Albert H. Fay. 24 pages. Technical Paper 176, Bibliography of Recent Literature on Flotation of Ores, compiled by D. A. Lyon, O. C. Ralston, F. B. Laney, and R. S. Lewis. 27 pages. Technical Paper 179, Preparedness Census of Mining Engineers, Metallurgists and Chemists, by Albert H. Fay. 19 pages. Monthly Statement of Coal-mine Fatalities in the United States, July, 1917. List of Permissible Explosives, Lamps, and Motors Tested Prior to August 31, 1917, compiled by Albert H. Fay. 27 pages. 8 pamphlets, 8vo. Washington, Government Printing Office, 1917.

U. S. Coast and Geodetic Survey: Results of Magnetic Observations Made by the Survey in 1916, by Daniel L. Hazard. 51 pages, quarto. Washington, Government Printing Office, 1917. Price, 10 cents.

CURRENT TOPICS

An Apparatus for Separating Visible from Invisible Light. W. S. Andrews. (*General Electric Review*, vol. xx, No. 10, p. 817, October, 1917.)—A flux of pure invisible light is necessary for the examination of the true fluorescent colors of fluorescent compounds or for other purposes. The author has constructed a simple and inexpensive apparatus for this purpose, based on a method of separating the invisible ultra-violet rays from visible light of a mixed spectrum described by Prof. R. W. Wood in a lecture before the Royal Institution of Great Britain in 1911. The apparatus consists essentially of a suitable light source, a quartz lens, a pinhole diaphragm, and a screen mounted along an axis in the order named. A light containing a large percentage of ultra-violet radiation may be produced by a high-tension disruptive spark between iron terminals.

The operation of this instrument, which naturally must be in a darkened room, is based on the fact that the mean focus of visible light is located at measurable distance beyond the mean focus of invisible ultra-violet light, owing to the greater refrangibility of the latter over that of the former. If, therefore, the diaphragm is adjusted to bring the pinhole into the exact mean focus of ultra-violet light, the rays of the latter will pass through the pinhole and spread out again on the other side of the diaphragm. The mean focus of visibe light being at some distance beyond the pinhole, these rays will be largely intercepted by the diaphragm, and only a few of the nearly parallel rays of visible light will pass through the pinhole. In operation, if the screen is made of non-fluorescent material, there will appear on it only a small illuminated spot, but if it is coated with a fluorescent substance, such as powdered willemite, the small luminous spot will be surrounded by a disk of bright green light produced by the fluorescence of the willemite excited by the circular field of the invisible ultra-violet rays. Should it be found desirable to eliminate the spot of visible light, a small metal disk can be set up in such a position as to cast its shadow over the spot and so transform it into a dark spot, leaving the disk of green fluorescent light otherwise unimpaired.

The apparatus resembles somewhat in general form an ordinary projecting lantern, and is valuable for determining the exact fluorescent colors of various compounds. When such compounds are exposed to the direct rays of an open iron spark, their true fluorescence is marked to a greater or lesser degree by the visible light component of the spark, this being especially the case with compounds that show only a weak intrinsic fluorescence. When a compound is placed within the field of the ultra-violet rays of this *separator*, it shows its true fluorescent color, and the passing it thus into a visually dark field and its becoming thereby illuminated produce a surprising and interesting effect.

The Spectroscopic Determination of Small Amounts of Lead in Copper. C. W. HILL and G. P. LUCKEY. (*Proceedings of the American Electrochemical Society,* October 3–6, 1917.)—A rapid method for the determination of lead in factory samples of copper depending upon spectroscopic observation has been under development by the authors. A known weight of copper is placed in a slight cavity in a lower positive graphite electrode, and a fixed or rotating carbon negative electrode is used above. A grating spectroscope serves to observe the spectrum. The time required to cause the disappearance of the bright lead line in the spectrum, or to cause its enfeeblement to a certain dimness, is measured with a stop-watch. With a carefully regulated arc, the times vary regularly with the amount of copper used and with its percentage of lead; *e.g.,* from 14 seconds with 0.2 gramme of copper containing 0.004 per cent. lead to 277 seconds with 1 gramme of copper containing 0.038 per cent. lead. The results are sufficiently reliable for practical use in the copper refinery.

The use of the arc is limited to the determination of small amounts of impurities which are volatilized at a comparatively low temperature in the presence of a metal which is not rapidly volatilized at a comparatively high temperature which gives a steady arc, the existence of strong characteristic spectrum lines being assumed. The method might be applied to metals of low boiling-point or even to salts by substituting a heating strip in place of the arc and securing the arc or spark spectrum from the vapors arising from the heating strip.

Extruded Metal. ANON. (*The Metal Industry,* vol. 15, No. 10, p. 435, October, 1917.)—Metal wire and rod made by the extrusion process is coming more and more into common use, according to the *Scovill Bulletin.* For many years wire and rod have been made by the drawing process in which the metal is pulled through dies, successively reducing its diameter or shape. Volume of production was limited at first by the time consumed in attempting to reduce the wire too much at one draft, which resulted in pulling the metal apart, and in the frequent annealings necessary to soften the wire. By the extrusion process the metal is pushed through the die while quite hot, thus overcoming at once the two limiting conditions of wire-drawing. The wire does not break because it is pushed through the die, and it does not get hard because it retains its softening temperature during the extruding. The process has been used in producing lead wire and lead pipe for a number of years. The problem of extruding lead, however, presents very few difficulties, as the softness of the lead allows it to be forced through the steel die cold.

For lead extrusion, the necessary equipment consists of a multiple plunger pump, a hydraulic accumulator, and a hydraulic press with attachments. Briefly these attachments consist of a heavy steel cylinder with a die-holding arrangement on one end, the other end being open to form a close fit to the plunger or ram of the hydraulic press. In extruding lead wire, a large piece of lead is placed within this cylinder and the press started. Lead wire will flow continuously from the hole in the die until the ram reaches the end of its stroke; it is then withdrawn for a new supply of lead. During the two strokes of the ram there occurs no break in the lead wire, the second supply of lead welding perfectly to what remains of the initial charge. In producing lead pipe, a long arbor is used, the point of which enters the die in such a way as to form a ring-shaped nozzle which determines the cross-section of the pipe.

Recognizing the possibilities of this process, experiments were made with the object of producing brass rod and wire by the extrusion process. Difficulties at once arose. It was found that to secure desired results, all the metal must be quite hot during the extruding, that hydraulic presses of great power were necessary, and that dies suitable for lead extrusion would not withstand the temperatures essential to successful results. These difficulties have, however, been overcome and a number of firms are now making brass rod by the extrusion process. A valuable feature of this process is the practicability of extruding the brass through odd-shaped dies to form certain cross-sections very expensive to obtain by other methods.

Largest Ingot Mould Ever Made. ANON. (*Mining and Scientific Press,* vol. 115, No. 15, p. 543, October 13, 1917.)—The largest ingot mould ever made has just been poured by the Bethlehem Steel Company at South Bethlehem, Pa. Its dimensions are 15 feet 7 inches high, with a mean diameter of 91½ inches, its shape being octagonal and corrugated. At its thinnest section or point of corrugation the thickness of the metal is 15 inches, and the heaviest section is 20¾ inches. A mould of this size is made so that steel can be poured into it to form ingots large enough to be reconverted into 16-inch and 18-inch guns. A steel ingot poured in this mould will weigh 300,000 pounds, and from it tubes and jackets for the large guns will be forged. Before the mould can be used large steel bands, 12 inches wide, must be shrunk around each end of the casting after it has cooled. Because of the necessity of pouring this large mould quickly, Bessemer pig-iron was melted in three large open-hearth steel furnaces and the melted iron suspended in ladles over the mould at one time. A continuous runner from the ladles was made so that the iron was thoroughly mixed before entering the mould. It took 340,000 pounds of pig-iron to pour the casting, not counting the 10,000 pounds needed later to fill up the sink-heads so as to take care of the natural shrinkage. The mould had to be left covered in the sand for a considerable time to completely cool. Two large

100-ton cranes were used to lift it from its pit and prepare it for transference to the open-hearth department, where it will be used regularly for casting ingots.

The French Official Horsepower Formula for Rating Automobile Engines. ANON. (*The Autocar*, vol. xxxix, No. 1145, p. 300, September 29, 1917.)—The question of a formula which will give some fairly approximate idea or reasonable basis of comparison of the power capacity of an internal-combustion engine has long been of interest. In England it is well known that for taxation purposes the Government adopts the R.A.C. formula, $D^2 \times N \div 2.5$, D being the cylinder diameter in inches and N the number of cylinders. The drawback to this formula is that no regard is paid to the question of the effect of varying piston stroke on the power development. According to *Cycle and Automobile Industries*, in France a new formula has been issued by the Ministry of Public Works, and is now being employed by the Service des Mines for determining the amount of annual tax payable by car owners.

The new formula is $H.P. = N \times K \times D^2 \times L \times n \div 60$; in which N is the number of cylinder; K a constant whose value is, for single cylinders 0.002, for two cylinders 0.00017, for four cylinders 0.00015, and for more than four cylinders 0.00013; D the bore in centimetres, L the stroke in centimetres, and n the number of revolutions for the maximum speed of the car on the level. While on the basis of equal bore and stroke the French formula gives a lower rating in the case of two- and four-cylinder engines than the British, the introduction of the stroke in the formula has a marked upward effect on the horsepower rating of the engines. It is apparent, however, that one of the drawbacks of the new French formula will be the problem of deciding as to the number of engine revolutions to be taken into account, the maximum speed of the car depending on many variable quantities..

Suggested Reforms in Some Chemical Terms. C. HERING. (*Proceedings of the American Electrochemical Society*, October 3–6, 1917.)—Physical chemistry has done so much for the benefit of chemistry that chemists should in return recognize, readjust, and redefine some of their terms to bring about a better concordance with physical chemistry and a better consistency in pure chemistry. The author's purpose is to point out some of these deficiencies and to suggest a few reforms which would help to systematize these terms, make them more consistent with each other and with modern developments, and to simplify the conceptions involved. The scope of the discussion is limited to that branch of chemistry in which electrons are involved, no attempt being made to embrace organic chemistry and the chemistry of non-electrolytes.

A number of recommendations are made. These are: A more precise distinction should be made between different kinds of *bonds*.

The term *valence* should be more strictly defined, and negative and zero valences should be included. A proposed practical unit for measuring electrons should be used. The *ionized* state should be considered as differing in kind from either the *free* or the *combined* state. *Reduction* should include all and only cases of reductions in valence, and *oxidation* all and only cases of an increase in valence, hence the new term *adduction.* The significance of the gaining and losing of electrons should be more clearly understood; the sign of electrode potentials is then more easily understood. As sometimes stated, Faraday's law is not a universal one; it is a corollary to a more basic one.

Cooling Underground Cables. ANON. (*Electrical World*, vol. 70, No. 15, p. 720, October 13, 1917.)—During the last summer a central station company in the Middle West which operates a rather extensive underground cable system made several experiments with the hope of discovering an effective means of reducing the operating temperature of its lead-covered cables. While none of the experiments developed any particularly successful method, the results of the experiments may be of some value to other companies contemplating similar tests. The first experiment, in which an attempt was made to cool the manholes and conduits by placing ice in the holes, was a failure. Each day for three days 200 pounds of ice was placed in each of three manholes. The centre manhole was on the top of a hill, and at that point a recording thermometer was stationed. The ice seemed to have no effect on the temperature, so the quantity of ice in each manhole was doubled. This did not affect the temperature, and the experiment was discontinued.

A forge blower fan was then placed in the previously mentioned middle manhole and was connected to a 6-inch sewer tile vent, which extended a distance of about 10 feet to the inside of the street curb. This fan was kept running 24 hours a day, exhausting approximately 300 cubic feet of air per minute. Although the fan exhausted a considerable quantity of warm air, the recording thermometers did not show any appreciable effect on the temperature of the manhole.

Following these experiments, it was decided to try cooling the cables by water. It was found that with a stream of water at 82° F., flowing at the rate of one gallon per minute, the temperature at the discharge end, which was 251 feet distant, was 108° F. On account of the condition of the cable in the district where this experiment was made, further investigation was considered unwise. It was therefore impossible to follow this apparently most successful investigation to a point that would give definite results.

Cracking Nuts by Centrifugal Force. ANON. (*Scientific American*, vol. cxvii, No. 13, p. 232, September 29, 1917.)—Palm oil and palm-nut kernels to the value of about $7,000,000 are imported annually by the United States, the bulk of which come from the west coast of Africa, small quantities from Mexico, and recently it has been discovered that palm nuts are also to be found in Central America. Prompted by the European war's effect upon shipments from Africa, and the difficulty experienced in developing business in Mexico on account of internal troubles, a company with headquarters in Los Angeles invaded Central America and is making preparations to develop the industry on a very extensive basis. This company started with about fifteen tons of machinery designed especially for the purpose.

The machine is a particularly clever device, in that it cracks nuts solely by centrifugal force. It is shaped somewhat like a drum and measures six feet in diameter. It stands, when the top feed and the bottom discharge have been added, nearly seven feet high, and weighs approximately 6000 pounds, the main casting alone weighing 3400 pounds. The nuts are conveyed in a steady stream to the hopper at the top, and from the hopper they drop into a fast-revolving drum-wheel, which throws them with great force against a continuous stationary belt of breaker-blocks lining the inside surface of the main, drum-shaped casting. A pressure of about 1800 pounds is required to crack them, as the nuts have an extremely hard shell, about a half inch thick. The drum-wheel, turning on a perpendicular-set axle, is speeded to 800 revolutions per minute and hurls the nuts on a tangent a distance of but two feet. This force is sufficient to break the shells into several pieces and release the kernels. Deflected by the downward-sloping surface of the breaker-blocks, the kernels and hulls drop toward the bottom of the machine, where they enter a discharge pipe and are separated from each other by a system of blowers. The machine has a capacity of about ten tons of nuts per hour.

The difficulty experienced heretofore in preparing these nuts for the market was the matter of cracking the hard inner shell. In Mexico this work is ordinarily done by hand, and is tedious and slow. The machine solves the problem very advantageously because of its greater capacity, and in that, by cracking the nuts by centrifugal force, the kernels, for the most part, remain whole and do not lose any of their oil. Preparations are also being made for the removal of the outer hull by machinery designed somewhat on the same principle as the large cracker. The only hand work will be the gathering, and this is usually done by raking the nuts into piles after they have fallen from the tree, or by cutting the bunches from the trees before they begin to fall.

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THE FORMATION OF CRYSTALS IN GELS.*

BY

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THE general properties of gels—or jellies—are familiar to us, but their inner structure is a matter of some dispute. J. M. van Bemmelin, Bütschli, and many others consider gels to be two-phase systems—a more concentrated solution as a network of cell-walls enclosing a more dilute solution of the same substance. The whole system is solid or semi-solid and extremely viscous. In the opinion of von Weimarn, the ultimate structure is minutely granular—even crystalline—and any coarser network is a secondary formation.

Emulsoids are two-phase liquids closely related to gels. In fact, emulsoids may change to solid gels by evaporation, cooling, or a change in the distribution of water, for example, between the two phases, thus altering their relative concentrations. Hot fluid emulsoids of agar or gelatine with water "set" to gels on cooling, but silicic acid gels set on the mere mixing of cold-water solutions of sodium silicate and a suitable acid. After standing some time the silicic acid forms two phases with the water, one more concentrated than the other, and when the proper distribution is reached solidification results. Manganese arsenate gels

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* Presented at a meeting of the Section of Physics and Chemistry held Thursday, January 25, 1917.

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so rigid they hold their shape, unaided, as well as any fruit jelly also set without cooling or evaporation. The gels of ferric arsenate and ferric phosphate set on dialysis—a removal of acids, bases, and salts.

As a preface to a study of crystal formation in any of these gels we must note their retarding the rates of diffusion of acids, bases, and salts, and their prohibition of diffusion of colloids. The mesh structure of gels must be practically equivalent to a network of capillary channels filled with the less concentrated phase. It follows, then, that the presence of substances affecting the distribution of water between the two phases must affect the size of these channels and change the rates of diffusion above mentioned. For example, Hatschek states that such salts as citrates and sulphates produce more rigid gels, but iodides and sulphocyanates retard or prevent gel formation. Bechold adds that sulphates, glucose, alcohol, and glycerol retard diffusion, while urea, iodides, and chlorides accelerate it.

The influence of certain gels—or jellies—on crystal growth is illustrated by many crystalline minerals. It is very probable that gelatinous silicic acid was the ancestor of quartz and by gradual dehydration became hard silica rock. In the gelatinous medium reactions took place under conditions favoring the formation of crystalline veins. For example, the reduction of gold salts produced crystals of gold, veining the gel, which later became quartz. A convincing part of this development can be reproduced in the laboratory.

To the geologist a working method of duplicating many such processes of Nature must be of great value. To the chemist a study of reactions in gels gives a useful control of relative concentrations and velocity of reactions. The pathologist finds in the subject some relation to the formation of crystalline material in animal tissue.

Silicic acid gels are discussed in this paper more than any other, but other gels function in a similar, though usually less effective, manner.

HISTORICAL.

E. Hatschek [1] did much important work in this field, attracted doubtless by the experiments of R. E. Liesegang. The latter observed that if a drop of silver nitrate solution was placed on a film of gelatine gel containing potassium dichromate the precipitated silver dichromate was formed in concentric rings separated by clear intervals. This "rhythmic banding" of "Liesegang's rings" will be discussed in a later paper. Whether a disk of gel or a tube partly filled with a gel be used, the essential feature is that one substance shall diffuse into a gel containing another substance, with which it reacts to form a rather insoluble compound. Rhythmic bands may form or, under different conditions, separate crystals of remarkable size and shape.

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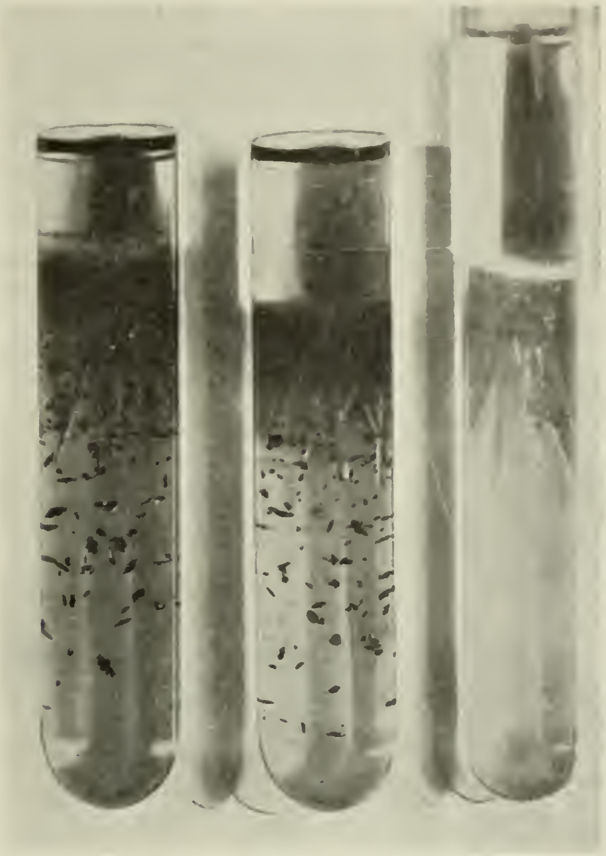
[1] *Kolloid Z.*, 8, 193 (1911); *Ibid.*, 10, 77 (1912); *Ibid.*, 10, 124 (1912); *Ibid.*, 10, 265 (1912).



Mixed crystals of silver sulphate—silver chromate with silver dichromate below.

Hatschek and Simon[2] reduced gold salts in silicic acid gels by the use of oxalic acid, ammonium formate, ferrous sulphate, sodium sulphite, carbon monoxide, sulphur dioxide, hydrogen, ethylene, etc. When illuminating gas was used as a reducing agent a black deposit of carbon always appeared mixed with the gold. Since graphite sometimes occurs with gold in quartz veins, this experiment is suggestive.

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[2] *Kolloid Z.*, 14, 115 (1914); *J. Soc. Chem. Ind.*, 31, 439.

Hatschek's usual method of work was to make a 5 to 20 per cent. gelatine gel or a 1 to 5 per cent. agar gel containing, for example, a small amount of potassium dichromate. This was allowed to solidify in a test-tube and covered with a solution of silver nitrate. The silver ion slowly diffusing down into the gel reacted with the dichromate ion to form silver dichromate in small crystals. In 1911 Hatschek reported these crystals 0.5 mm. long in 10 per cent. gelatine; lead dichromate 0.03 mm. long in 2 per cent. agar; lead chloride 2 mm. long in agar; barium carbonate 0.1 mm. long in 5 per cent. gelatine; potassium sulphate 0.2 mm. long in 5 per cent. gelatine. He also prepared a number of other crystalline compounds, such as lead iodide, lead sulphate, lead chromate, calcium sulphate, and barium silicofluoride. Later he used silicic acid gels as the media for diffusion, and obtained larger crystals. In 1913 he reported lead chloride crystals 15 mm. long. He was unable to make crystalline sulphides in gels.

His reduction of gold chloride in silicic acid with oxalic acid yielded beautiful crystalline gold and, by varying the conditions, colored colloidal gold.

Hatschek held that the concentration and nature of the gel determined the form and size of the crystals. The inelastic gels like silicic acid, he thought, were superior to the elastic organic gels like agar and gelatine. He wrote of " the practically universal tendency to form spherical bodies in agar and gelatine," although he did obtain some crystals in these media.

Hatschek [3] made gels of silicic acid by mixing sodium silicate solutions with hydrochloric acid. The diffusion of a lead salt into this gel formed crystals of lead chloride. In similar fashion he treated sodium silicate with sulphuric acid and caused lead or calcium salts to diffuse into the gel, thus forming crystalline sulphates of lead or calcium. With phosphoric acid gels he obtained crystalline phosphates of copper, calcium, and strontium.

Simon [4] grew the well-known " lead tree " in a silicic acid gel containing lead acetate. A bit of zinc or tin was pressed into the top of the gel. I found that if the gel is about 0.02 N with respect to lead acetate a splendidly branching tree grows and may be handled roughly, since it is supported on all sides by a solid.

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[3] *Kolloid Z.*, 10. 77 (1912).

[4] *Ibid.*, 12, 171 (1913).

Pringsheim[5] states that when two salt solutions diffuse into a gel in opposite directions the reaction does not proceed beyond a thin film if the solutions are isotonic. A hypertonic solution continues to diffuse into a hypotonic, and any precipitate formed is deposited in the latter. In accord with this idea, Hatschek often added indifferent substances to the solution on top of the gel in order to insure reaction below the gel surface.

Liesegang[6] found that the older opinion that growth of a precipitate in a gel was limited to one side of the initial precipitation film did not hold for quinol on silver nitrate. I confirmed Liesegang's finding by several new examples. He also obtained silver crystals in gelatine by reducing silver nitrate with ferrous sulphate.

Gerhart[7] placed a solid reacting substance in a test-tube, covered with a mixture of water-glass and a suitable acid before the gel set, and, after it became solid, poured a solution of the second reacting substance on top. Both salts then diffused into the gel and met. Gerhart found alum and potassium nitrate to have considerable influence on the form of crystals deposited.

Hausmann[8] obtained crystalline halides of thallium in gelatine.

Dreaper[9] dispensed with a gel as a medium for reactions and used a single capillary tube. For example, a capillary tube filled with 3 per cent. lead acetate was immersed in 5 per cent. hydrochloric acid. Crystals of lead chloride nearly 1 mm. long formed in the capillary. Sand in wide tubes functioned the same as a single capillary. Dreaper considered relative rates of diffusion and concentration of the incoming solution the determining factors.

Ernest Marriage[10] studied the arrangement and size of lead iodide crystals in fruit gels and jams. The various fruit jellies and jams influenced the precipitation of lead iodide in different ways, and use was made of this fact in detecting adulteration of commercial products.

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[5] *Z. phys. Chem.*, **17**, 473 (1895).

[6] *Kolloid Z.*, **17**, 141 (1915).

[7] *Tsch. Min. Mitt.*, **28**, 347 (1908); *Ibid.*, **29**, 185 (1910).

[8] *Z. anorg. Chem.*, **40**, 110 (1904).

[9] *J. Soc. Chem. Ind.*, **32**, 678 (1913); *Kolloid Z.*, **14**, 163 (1914).

[10] *Kolloid Z.*, **11**, 1 (1912); *Sci. Am. Sup.*, **77**, 375 (1914).

De Schulten,[11] by the slow admixture of extremely dilute solutions of barium chloride and sulphuric acid, obtained crystals of barium sulphate that in a month measured 5 mm.

Deiss[12] prepared a gel of $MnHAsO_4$ by mixing equal volumes of 10 per cent. $MnCl_2$ and KH_2AsO_4. On standing three months, rose-colored crystals of the same composition as the gel separated.

Zinc-ammonio chloride crystals lining a dry cell.

Kohler,[13] in a study of " rhythmic crystallization of sulphur," states that " the viscosity of the liquid must be so great that the rate of flow towards the crystallizing part is slower than the rate of crystallization." This compares with slowness of diffusion in a gel.

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[11] *Compt. rend.*, 136, 1444 (1903).

[12] *Kolloid Z.*, 14, 139 (1914).

[13] *Ibid.*, 17, 10 (1915).

Shulansky and Gies[14] observed that "in the putrefaction of meat crystals of ammonio-magnesium phosphate appear early and accumulate rapidly," due to bacterial activity. This paper and a similar one by Perlzweig and Gies[15] may have some bearing on the subject because of the hydrated colloid nature of animal tissue.

Creighton[16] added the influence of a weak current of electricity to the process of diffusion in gelatine. Using an iron anode and a gel containing potassium ferricyanide, Turnbull's Blue appeared in stratified layers—not crystalline, however. Braun[17] believed that certain phenomena attending the formation of sulphides and the deposition of copper in capillary spaces previously noted by A. C. Becquerel are of an electrochemical nature, as Becquerel[18] had suggested: "Sur des noveaux effets chimique produits dans les action capillaire." These phenomena are partly dependent, according to W. Ostwald,[19] on the semipermeability of precipitated membranes.

In a paper on "Electrostenolysis," H. N. Holmes[20] reported on electrocapillary action in insoluble powders.

The observation of Henri Becquerel that solutions of copper sulphate and sodium sulphide meeting by diffusion through a fine crack in a glass tube formed minute crystals of copper sulphide relates to Dreaper's experiment with the single capillary.

Cornu's great series of papers[21] on the significance of gels in geology are an important part of the literature.

As will be shown elsewhere in this paper, slow diffusion processes in the earth's crust have much to do with the formation of crystalline mineral deposits. John Clark,[22] in "A Chemical Study of the Enrichment of Copper Sulphide Ores," gives a suggestive account of the reducing action of hydrogen sulphide and amorphous sulphur.

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[14] *Biochem. Bull.*, 3, 45 (1913).

[15] *Ibid.*, 3, 69 (1913).

[16] JOURNAL OF THE FRANKLIN INSTITUTE, 182, 745 (1916).

[17] *Ann. der Physik und Chemie*, 44, 507 (1891).

[18] *Compt. rend.*, 64, 919 (1867); *Ibid.*, 65, 51, 720 (1867); *Ibid.*, 66, 77, 245, 766, 1066 (1868); *Ibid.*, 67, 1081 (1868).

[19] *Z. phys. Chem.*, 6, 75 (1890).

[20] *J. Am. Chem. Soc.*, 36, 784 (1914).

[21] *Kolloid Z.*, vols. 1–5.

[22] *Bull. Univ. of N. Mex.*, 1, 79 (1914).

W. H. Emmons,[23] in a similar paper on "The Enrichment of Sulphide Ores," remarks, "To the chemist this paper is an appeal for more experimental data on the important mineral syntheses involved in the process."

P. Krusch[24] investigated primary and secondary ores with especial reference to the gel and the rich heavy metal ores.

Interesting changes in glass structure are given in U. S. G. S. Monograph 32, on "Spherulites and Lithophyse," and in a paper published by George H. Williams in an early issue of the *Johns Hopkins Circular*.

Johnston, Merwin, and Williamson,[25] discussing "The Several Forms of Calcium Carbonate," state that "aragonite is precipitated, as is well known, even at ordinary temperatures in a solution of a salt from which a carbonate isomorphous with aragonite may be precipitated. Aragonite is precipitated in the presence of a lead salt formed around nuclei of cerussite ($PbCO_3$) in parallel orientation." It seems to me that these authors might well try the precipitation of calcium carbonate in a neutral gel containing a lead salt. Crystals of unusual size might be obtained and thus facilitate their study.

Doelter[26] considers that practically all substances are colloidal when first precipitated. What we call amorphous bodies are very close to the crystalline. The tendency to pass from the colloidal to the crystalloidal condition is greatly influenced by pressure, shock, light, and long-continued heating. Doelter proved his point by laboratory experiments. He was led to declare that minerals whose formation was once thought to require high temperatures may easily be formed without such temperatures.

Stephen Taber,[27] in "The Origin of Veins of Asbestiform Minerals," makes a valuable contribution to the study of crystal growth. "The shape of a growing crystal is controlled by one or more of three independent factors, namely: (1) The tendency to assume a regular polyhedral form because of the forces of surface tension and molecular orientation; (2) the relative and absolute magnitude of the external forces resisting growth in different directions; and (3) the accessibility of the material from which the crystal is built. As a result of the first factor some substances normally crystallize in slender, acicular or hair-like forms, but an asbestiform structure is never produced without the assistance of one of the other two factors. Crystal growth under unequal pressure undoubtedly explains the development of fibrous structure in some instances. The solubility of most substances increases with the pressure, and therefore crystal growth may be limited to the direction of least pressure. This hypothesis is not applicable, however, to fibres that develop normal to the walls of the vein. Moreover, the veins frequently intersect and run in all directions through a given rock mass. Such occurrences of abnormal fibrous structure must therefore be attributed largely to the circumstance that the material for growth was accessible only in one direction."

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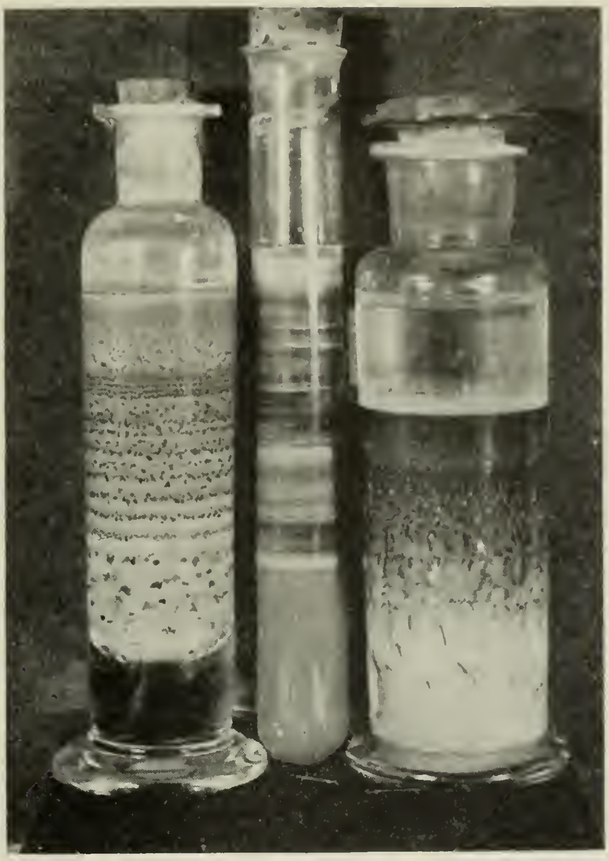
[23] *Bull. U. S. G. S.*, No. 529, 11.

[24] *Min and Sci. Press*, 107, 418 (1913).

[25] *Am. J. Sci.*, 41, 473 (1916).

[26] *Kolloid Z.*, 8, 29, 86 (1911).

[27] *Nat. Acad. Sci.*, 2, 659 (1916).



Basic mercuric chloride in silicic acid containing an excess of base.

In another paper on "Pressure Phenomena Accompanying the

Growth of Crystals" Taber[28] remarks: "Crystallization is retarded or prevented in supersaturated solutions which occupy small capillary or subcapillary spaces; therefore crystals may be supplied with material for growth by diffusion through solutions occupying such spaces, and the increase in volume due to the entrance and deposition of new material must result either in the expulsion of part of the solution or the enlargement of the space occupied by the growing crystals. . . . Crystals grow in directions in which external forces oppose growth whenever the surfaces under pressure are in contact with a film of supersaturated solution, and it is possible to supply the material for growth by slow diffusion through subcapillary spaces, as great resistance is offered to the expulsion of solution from such openings. The conditions requisite for crystal growth under pressure commonly obtain in the rocks of the earth's crust, and many phenomena connected with the metamorphism of rocks, the growth of concretions, and the formation of mineral deposits are difficult of explanation under any other hypothesis than that growing crystals have made room for themselves by exerting pressure on the surrounding material."

METHODS OF WORK.

I found it convenient to mix equal volumes of solutions of sodium silicate and some acid, pouring the water-glass into the acid and mixing quickly and thoroughly. Before the silicic acid set to a solid one of the reacting salts was mixed with this solution, which was then poured into test-tubes. After the gel set, the other salt solution designed to react with the first was poured on top. The solution on top should have a greater osmotic pressure than the gel to insure reaction within the gel instead of above the surface.

The water-glass used was a commercial grade known as "water white," with a density of 1.375. The ratio of the Na_2O to the SiO_2 was 1 to 3.5. When diluted to a density of 1.06 and titrated against hydrochloric acid, using phenolphthalein as an indicator, it was equivalent to 0.51 N acid. With methyl red as indicator the normality was 0.57.

This particular water-glass was used at the 1.06 density for many experiments because weaker solutions were too slow in the set of the silicic acid. With this concentration an equal volume of N acetic acid was suitable for most of the experiments. Such a gel set over night and contained a small excess of acid. It was reasonably clear. This rather arbitrary selection really marked the lowest concentration limit for working convenience. Acetic acid, 0.75 N, serves as well and gives less excess acid. Several other acids were used for special purposes, but the time of set varied with the acid. A partial list follows:

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[28] *Ibid.*, 3, 297 (1917); *Am. J. Sci.*, 41, 532 (1916).

1.06 density sodium silicate with equal volume N acetic acid set in 6 hours.

1.06 density sodium silicate with equal volume N formic acid set in 36 hours.

1.06 density sodium silicate with equal volume NN phosphoric acid set in 10 minutes.

1.06 density sodium silicate with equal volume N hydrochloric acid set in 10 days.

1.06 density sodium silicate with equal volume N sulphuric acid set indefinite.

1.06 density sodium silicate with equal volume N nitric acid set in 4 weeks.

This applies only to the particular water-glass described above. Considering convenience in time of set, clearness of the gel, and failure to split as the gel contracts, the following table will be found more useful, except in respect to acetic:

1.16 density sodium silicate with equal volume 3 N acetic acid set in 1 hour.

1.08 density sodium silicate with equal volume of 3 N formic acid set in 48 hours.

1.06 density sodium silicate with equal volume 2 N hydrochloric acid set in 5 days.

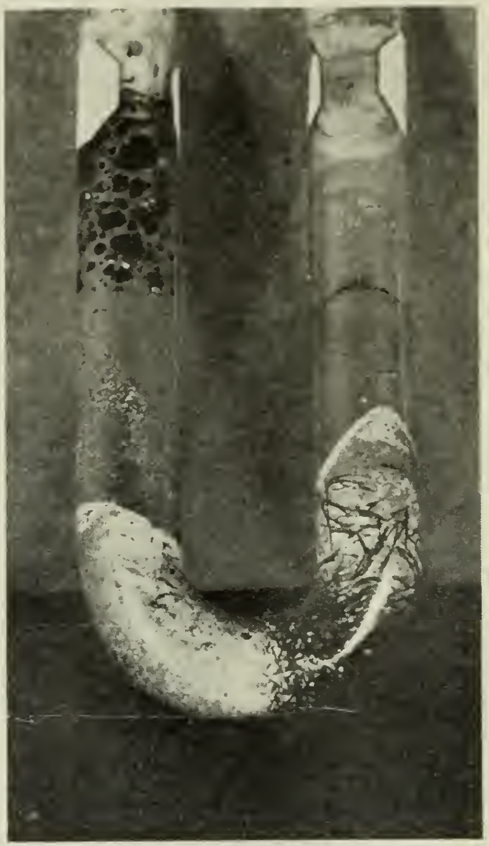
1.06 density sodium silicate with equal volume 6 N sulphuric acid set in 1 day.

1.10 density sodium silicate with equal volume 2 N nitric acid set in 2 days.

Temperature changes affect the time of set considerably. I made a few tests with water-glasses of different composition and found it possible to get good results with them also. In one the ratio of Na_2O to SiO_2 was 1 to 2, its density 1.69, and, diluted to 1.06, the solution was equivalent to 0.67 N acid with phenolphthalein as indicator. In another the ratio of Na_2O to SiO_2 was 1 to 4, the density 1.34, and, diluted to 1.06, the solution was equivalent to 0.46 N acid.

New tables of time of set should be constructed on the basis of the normality of the particular water-glass at hand. For example, a 1.06 water-glass equivalent to 0.67 N acid must be mixed with an equal volume of more than N acetic acid to give results similar to those in the table.

Pouring the mixture before it solidifies into the bend of a U tube gives the experimenter excellent control of conditions. The two reacting solutions poured separately into the arms of the U tube slowly diffuse through the gel and meet, often forming a sharp precipitation band. Any amount of either solution can be used in this method.



Silver dichromate crystals in alundum powder.

Hatschek, in some of his work, directs that the mixture of water-glass and acid be dialyzed to free it from excess acid and salts. Addition of very little ammonia sets the gel. In other experiments he did not dialyze. I do not find it necessary or desirable to dialyze out the acid and salts. Their influence on crystal formation or development of banding is beneficial in most instances. In a number of experiments I used a large excess of acid, and in others added salts or non-electrolytes to secure certain effects.

Doryland[29] suggested that a mixture of water-glass and just enough acid to make a neutral solution would set to a gel in minimum time. Traube and Kohler[30] came to a similar conclusion in regard to the effect of acids and bases on gelatine. This led me to make basic gels by using less acid than enough to neutralize the sodium silicate. In this way a very profitable field of investigation was opened up. Basic salts, for example, may not be studied in gels containing excess acid. A mixture of equal volumes 1.06 density water-glass and 0.5 N acetic acid is very slightly basic and sets in about three minutes. Other water-glasses must be titrated to get similar figures.

EXPERIMENTAL PART.

Hatschek's gold was so interesting and spectacular that it seemed advisable to vary his methods. He used a sodium silicate-hydrochloric acid gel with oxalic acid as a reducing agent. Phosphorus in ether, as well as a number of other reducing substances, was also tried by Hatschek.

After duplicating a number of his results I varied the acid used in making the silicic acid gel and secured by far the most spectacular effects when the gel was made by mixing sodium silicate with sulphuric acid. That this was due in part to the presence of sulphate was proved by comparing an oxalic acid reduction of gold chloride in a water-glass-acetic acid gel with a similar one containing, in addition, considerable sodium sulphate. The first gave very little crystalline gold—mostly the colored colloidal form. Addition of soluble sulphate developed a few color bands in the second.

To secure a dazzling display of gold crystals which gleam brilliantly in the sunlight, I found the best way was to mix equal volumes of 1.06 density sodium silicate and 3 N sulphuric acid. To 25 c.c. of this mixture 1 c.c. of 1 per cent. gold chloride was added. This gel set in about one week. Then the solid gel (in a test-tube) was covered with 8 per cent. oxalic acid solution. In several hours the crystal growth was marked, and in a few days at its best.

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[29] Private communication.

[30] *Intern. Zeitsch. phys.-chem. Biol.*, 2, 42 (1915).

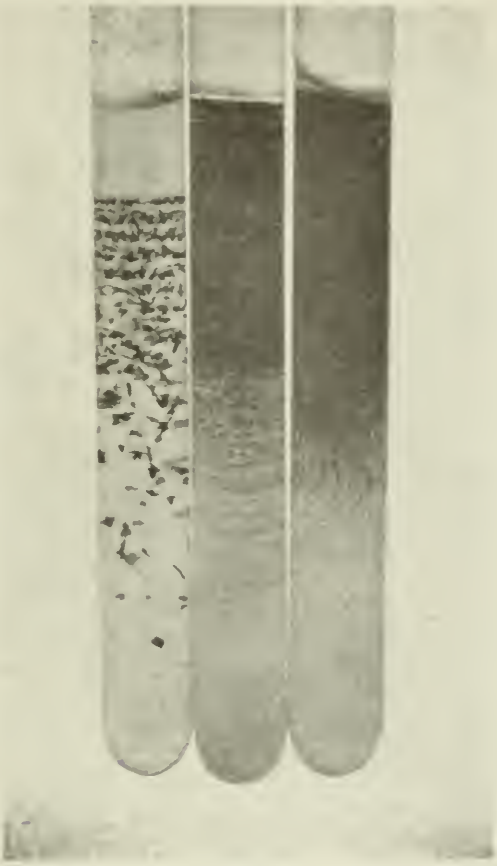
A remarkable difference appeared when 1.16 density water-glass was used instead of 1.06 with the 3 N sulphuric acid. With the same reducing solution—8 per cent. oxalic acid—a series of splendidly colored bands of colloidal gold was obtained. The upper layer of the first bands was red, below that blue, and below that green. A comparatively clear gap below this was followed by another red-blue-green zone. Usually after the first few rainbows the red was omitted. A dozen or more such bands in an ordinary test-tube were not uncommon—the upper bands measuring about 1 cm. in depth. Golden crystals were dispersed all through these gels, but it should be noted that the 1.06 water-glass-3 N sulphuric rarely developed colored colloidal gold—only the yellow crystals.

Many variations in concentrations were tried. Excellent results were obtained with 0.5 c.c. of 1 per cent. gold chloride in 25 c.c. of gel, but 2 c.c. was not so good, and with much less than 0.5 c.c. the gold was too thin. Even 2 per cent. oxalic acid was effective as a reducer, but a saturated solution—about 8 per cent.—was most satisfactory. A very little gum tragacanth mixed with the gel to reduce the gold chloride resulted in blue colloidal gold uniformly distributed.

Copper.—Perfect tetrahedrons of metallic copper were obtained in a 1.06 water-glass-N acetic acid made 0.05 N with respect to copper sulphate. The gel was covered with a 1 per cent. solution of hydroxylamine hydrochloride. In a week or two the tetrahedrons were large enough to observe with the unaided eye. Those formed near the surface were much smaller than those at greater depths. Of course, the farther the reducing solution diffused into the gel the more dilute it became. In a beam of sunlight the faces of the tetrahedrons gleamed with a splendid copper lustre. In nearly all experiments one or more groups of overlapping tetrahedrons were noted. These formed in three radiating lines, making angles of 120 degrees, or in some instances of 60, 120, and 180 degrees. This arrangement of copper crystals is found in mineral deposits. All the other reducing solutions tried were inferior to hydroxylamine.

The presence of small amounts of glucose, cane-sugar, alcohol, or glycerol in the gel caused the formation of a good deal of red feathery stuff. The presence of sodium sulphate aided crystallization.

With a basic gel very different results were obtained. Glucose—a few grammes of 25 c.c.—was mixed with a 1.08 waterglass-0.5 N acetic acid gel and covered with 0.5 N copper sulphate. After a few months close bands of rather amorphous cuprous oxide extended down the gel for a distance of about 12 cm. At first the bands were yellow, but as they aged they turned to a dull red. At one time both colors were in evidence, the newer bands yellow. Near the surface of the gel a blue deposit of cupric hydroxide formed. This reaction is suggestive of Fehling's test for glucose. Of course, no copper complex is used here, but evidently slow diffusion permits the reduction from cupric hydroxide to cuprous oxide.



The influence of chlorides on the distribution of mercuric iodide. The tube at the left contains sodium chloride—the others do not.

It has been suggested that this method gives opportunity for studying a reaction in its various stages. The control of concentrations and the rates of diffusion pave the way.

Using a U tube containing a 1.10 water-glass-0.5 N acetic acid gel in the bend and 0.5 N copper sulphate in one arm and 1 per cent. hydroxylamine in the other, blue-white bands with a yellow front appeared, later red cuprous oxide, and, finally, red tetrahedrons of metallic copper.

Silver Dichromate.—A 1.06 water-glass-N acetic acid gel was set in the bend of a U tube and the arms filled with 0.1 molar silver nitrate and 0.1 molar potassium dichromate. Minute dark-red crystals soon formed. In one test-tube experiment a single crystal of silver dichromate measured 5 × 5 × 1 mm. This was after a few months' growth. In a U tube experiment a thin red sheet, 1 cm. long, was found—so thin that it was a clear red by transmitted light. Thicker crystals were almost black. The presence of very little gum tragacanth or starch in one of these gels hindered the formation of good crystals and favored the development of spherulites.

Lead Iodide.—Lead iodide crystals had been made by other investigators, but merited further study. This is one of the easiest to make and most spectacular of all the crystal exhibits. A 1.06 water-glass-N acetic acid mixture containing 2 c.c. of N lead acetate to every 25 c.c. was poured into test-tubes. After the silicic acid gel set firmly it was covered with 2 N potassium iodide. A compact layer of lead iodide quickly formed on the surface, followed very soon by crystallization below the surface of the gel. In a few days fern-like fronds grew down into the gel, mixed with many hexagonal plates. These concentrations may be varied with interesting results, and the lead salt may be used above the gel with the potassium iodide in the gel. The first order is much better. Magnificent golden fern fronds, 8 cm. in length, and nearly perfect hexagons, 5 mm. in diameter, were obtained in some experiments. In one or two tubes six hexagons grouped around a centre much like the arrangement in some snow crystals. On standing in direct sunlight for several months the lead iodide crystals blacken somewhat.

Using an excess of the lead acetate as compared with the potassium iodide, for example, in U tubes pouring 0.25 N lead acetate in one arm and 0.1 N potassium iodide in the other, with a gel separating the solutions, yellow-white needles and blocks of basic lead iodide formed. Some of the needles were 2 cm. in length. Watts[31] states that if lead acetate in excess is mixed with potassium iodide the basic iodide forms unless sufficient acid is present to prevent. With lead nitrate the ordinary lead iodide results. When formed very slowly, the yellow-white needles and blocks gleam brilliantly and seem to have a high index of refraction. Star-shaped groups and crossed stick arrangements were common. This is not the white double salt ($PbI_2.KI.2H_2O$) made by Remsen and Herty[32] by the action of excess potassium iodide on lead iodide.

In U tube experiments such concentrations as 0.25 N lead acetate and 0.1 N potassium iodide formed both the ordinary yellow hexagons and, in the arm nearer the lead acetate, the white-yellow basic crystals. In fact, these concentrations could be so varied as to give, first, only the yellow crystals of lead iodide, with a later formation of the white-yellow basic iodide. As the lead acetate diffused through the gel and met the potassium iodide these yellow hexagons formed, and later, as excess lead acetate diffused into this zone, the white needles or blocks developed. Often a basic crystal formed, touching the edge of a yellow hexagon, and apparently "ate it up" as the excess lead acetate reached that point. With such proportions in the U tube as 0.25 lead acetate and N potassium iodide only the yellow hexagons of the normal iodide form.

In a slightly basic gel, such as 1.06 water-glass-0.5 N acetic, the formation of the white needles of the basic iodide was greatly favored. Dropping acid on these basic crystals instantly turned them yellow, forming the normal iodide. Using 0.25 N solutions of both lead acetate and potassium iodide in a U tube, a 1.06 water-glass-0.5 N acetic acid gel developed white needles in two days, growing to a length of 2 cm. in one week; a 1.06 water-glass-N acetic acid gel developed yellow hexagons in two days, and in one week white stars also appeared; a 1.06 water-glass-2 N acetic acid gel developed yellow hexagons in two days, and in several weeks no white crystal of the basic salt appeared. The last gel was too acid for a basic salt, while the first gel had a slight alkaline reaction.

A little starch paste mixed with a 1.06 water-glass-N acetic acid gel produced a most interesting result. The gel turned blue around the individual crystals, proving the release of free iodine. It cannot be urged that the excess acid formed hydrogen iodide which was oxidized by dissolving oxygen, for in that event the gel would have turned a solid blue. It is possible that the starch intimately mixed with the lead iodide as it formed reduced part of it to lead subiodide. There is no question about the existence of a subiodide of lead as recently proved by Denham.[33]

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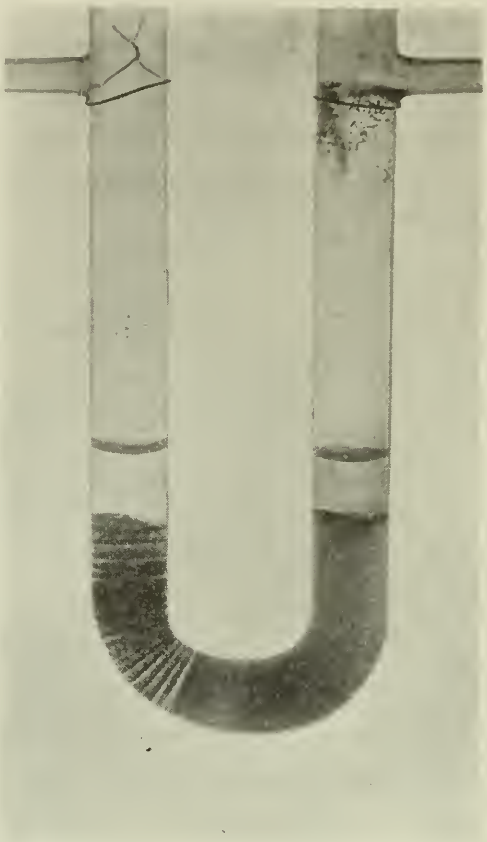
[31] Dictionary of Chemistry, iii, 127.

[32] *Am. Chem. J.*, 14. 107 (1892).



Rhythmic bands of mercuric iodide in a silicic acid gel.

A very little gum tragacanth in the silicic acid gel caused the appearance of spherulites of lead iodide and greatly hindered crystallization. In scores of experiments lead iodide showed no tendency to band in silicic acid gels, although in agar well-marked bands of crystalline aggregates were the rule. Hatschek reports bands of lead iodide in silicic acid gels when he used tap-water in preparing solutions, attributing the effect to the bicarbonates present in the water.

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[33] *J. Chem. Soc.*, 29 (1917).

Lead bromide in white twin crystals was prepared by experiments similar to those with lead iodide.

Mercuric Iodide.—A 1.06 water-glass-N acetic acid gel with a 0.1 N content of potassium iodide was covered with a saturated solution of mercuric chloride—approximately 0.5 N. At once a layer of red mercuric iodide formed on the surface of the gel, and later scarlet needles in a more or less banded arrangement, depending on relative concentrations. Some of these needles grew to one centimetre in length. Separate cubes of mercuric iodide were observed in some tubes. With a suitable concentration of potassium iodide in the gel, the growing mass of red crystals developed a yellow front, bounded by a sharply marked surface. This zone of yellow needle crystals advanced down the tube. In reality a new yellow zone formed and the old turned red.

An excess of mercuric chloride reacted with the red mercuric iodide to form a somewhat soluble double salt. As a result, the first zone of red crystals formed in the upper part of the gel finally disappeared as the excess of mercuric chloride from the solution above reached this zone. Reversing the order, mixing the mercuric chloride in the gel and allowing the potassium iodide to diffuse down into the gel, produced a mass of red crystals as before, but the red zone advanced down the tube at a rapid rate. In reality a new front formed and the excess potassium iodide readily dissolved the rear of the mercuric iodide column.

With suitable concentrations wonderful banding of red mercuric iodide was obtained. Some tubes contained 40 bands in a distance of 8 cm. The spaces between the denser bands contain scattered crystals. The U tube method was very useful here. Red bands advanced around the bend as the excess of mercuric chloride diffused into the gel. When sufficient mercuric chloride was supplied the red bands finally disappeared, leaving alternate opaque white and clear spaces in a replica of the original banding. Mercuric nitrate diffusing into similar gels produced much better banding than did mercuric chloride, possibly due to the difference in ionization. The presence of sodium nitrate aided banding considerably, as did sugar.

Sodium chloride showed a striking influence on the arrangement and form of the crystals of mercuric iodide. In proportion to the amount of sodium chloride added to the silicic acid gel the crystals of mercuric iodide became much larger and more like cubes than needles. They were farther apart, and less of the banding arrangement was noticeable. In another series of experiments the acetic acid was dispensed with in making the gel. Water-glass of 1.06 density and 2 N hydrochloric acid made 0.1 N with respect to potassium iodide was poured into tubes, and, after the silicic acid became solid, was covered with saturated mercuric chloride. The red crystals of mercuric iodide formed were very large, relatively, far apart, and no bands could be seen. This change was due to the influence of chlorides, for sodium chloride was formed in the reaction making the gel and, in addition, an unusual excess of hydrochloric acid was present. With less of the same acid the change was not so marked.

A little starch paste in the silicic acid gel caused the appearance of blue around the individual crystals, proving—as with lead iodide—the presence of free iodine at the surface of the crystals. This, too, may be a reduction of the mercuric iodide by the starch.

Basic Mercuric Chloride.—In attempting to make mercuric iodide in a slightly basic gel, 1.08 water-glass-0.5 N acetic, magnificent brown-black leaves were observed, some of them 2 cm. in length. These leaves appeared in the arm of the U tube containing the mercuric chloride. They formed very soon before any potassium iodide could diffuse into that part of the gel. Other mercuric salts gave no such result, so to test the matter I poured a basic gel, 1.08 water-glass-0.5 N acetic into a test-tube and with no other added salt covered the gel with saturated mercuric chloride solution. The same shining red-brown leaves appeared. Since they could not be obtained in a gel of acid reaction nor with any salt other than mercuric chloride, they were evidently one of the basic mercuric chlorides. A search of the literature justified this theory. Different basic chlorides are on record, but the description of $HgCl_2.2HgO$ agrees perfectly with the crystals obtained above.

Gels of different basicity were covered with mercuric chloride solution and the crystals compared. With 1.06 water-glass-0.5 N acetic (very slightly basic) the crystals were more widely scattered and, at a distance of a few centimetres from the surface of the gel, were excellent. This particular gel caused the most remarkable banding of the basic chloride. With a very basic gel the crystals were smaller and formed in a rather compact mass. A few grammes of glucose in 25 c.c. of a slightly basic gel changed the results decidedly. Instead of the brown-red leaves, a gray mass of closely-packed bands, sharply marked, appeared. In a distance of 8 cm. over one hundred of these bands were counted.

Silver Sulphate.—An attempt was made to produce silver dichromate by allowing N silver nitrate to diffuse into a silicic acid gel containing very dilute potassium dichromate. This particular gel was the result of mixing 1.06 water-glass with 3 N sulphuric acid instead of the usual acetic acid. Immediate formation of bright-red crystals at the top of the gel was observed, and later the usual black-red silver dichromate deeper in the gel. Curiously enough, the bright-red crystals were of an entirely different system, orthorhombic, from the triclinic silver dichromate below. They grew rapidly—in less than one hour their shape was apparent, and over night they grew to a length of one centimetre. In a week or two, by using more concentrated silver nitrate, slabs 3 cm. long were obtained, but in spite of their thickness they were a clear cherry red. Using 0.1 N silver nitrate no such orthorhombic crystals formed, only the ordinary silver dichromate. The gel had to be made with sulphuric acid and water-glass. This suggested a double salt formed with the excess of silver nitrate, but the difficulty was readily cleared by analysis and further experiment. Analysis showed the red orthorhombic crystals to be almost entirely silver sulphate, with a very little silver chromate mixed in.

Chamot [34] states that both silver sulphate and silver chromate are orthorhombic, hence these must be mixed crystals. Gooch [35] and Autenrieth [36] observe that silver chromate is formed when excess silver nitrate reacts with a soluble dichromate, hot or cold. To test the mixed crystal explanation, I omitted the potassium dichromate in another experiment and secured colorless slabs exactly like the cherry-red ones in shape and time of formation. Furthermore, by the presence of a single drop of a potassium dichromate solution in a tube of the gel a faint yellow color was made to appear in the slabs. Their depth of color was easily made to vary with the concentration of the potassium dichromate. No doubt this experiment could be extended to many other pairs of isomorphous substances. The conclusion is that when approximately N solution of silver nitrate diffuses into a silicic acid gel made from 1.06 water-glass and 3 N sulphuric acid containing any small amount of a soluble dichromate mixed crystals—not a double salt—of silver sulphate and silver chromate result. As the silver nitrate becomes more dilute at greater depths in the gel only the normal silver dichromate forms.

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[34] "Elementary Chemical Microscopy," 335.

[35] "Methods in Chemical Analysis," 406.

[36] *Ber.*, 35, 2057.

Basic lead iodide in a silicic acid gel.

Silver Acetate.—The silver sulphate experiment is very similar to one with silver acetate. Increasing the concentration of silver nitrate to N in making a silver dichromate, I found that gels made from acid and water-glass soon showed long, colorless slabs or leaves. Omitting the potassium dichromate from the experiment, and simply allowing N silver nitrate to diffuse into a 1.06 water-glass-N acetic acid gel, the same colorless leaves were produced again. Analysis showed them to be silver acetate. In ten minutes these crystals grew a few millimetres in length, and over night to one centimetre.

By varying the acid mixed with the water-glass in making the silicic acid gel and allowing approximately N silver nitrate to diffuse in, many silver salts can be obtained in crystalline form. This principle was applied by Hatschek to other compounds.

Silver phosphate formed in this manner (1.06 water-glass to 3 N phosphoric acid) grew in irregular yellow fronds, very much like minute ostrich plumes.

Acid potassium tartrate crystals grew rapidly when a 1.16 water-glass-3 N tartaric acid gel was covered with any dilute potassium salt solution. Blocks 5 mm. wide resulted, and in several hours crystals of notable size could be counted on. Changing the concentrations somewhat, wide-branching fern growths were obtained.

Dihydrogen monosodium phosphate crystals formed when about 3 grs. of disodium phosphate were mixed with 10 c.c. of a 1.10 water-glass-2 N acetic acid gel. In a cool room perfect colorless rhombohedrons appeared in a few hours and grew to 6 mm. width in two days. These crystals were so soluble that as the room warmed they dissolved. On cooling in the ice-box they appeared again, but not in such good crystals. Some of the attempts to duplicate this experiment failed. Exact temperature and concentration conditions were not studied.

Urea nitrate crystals of large size formed rapidly when concentrated nitric acid mixed with an equal volume of water diffused into a 1.06 water-glass-N acetic acid gel containing urea.

Lead chromate and basic lead chromate developed in a slightly basic gel such as 1.06 water-glass-0.5 N acetic acid containing a little potassium chromate when lead acetate solution diffused into the gel. In a few weeks a 15-cm. test-tube filled with orange tendrils curling around countless brighter yellow crystals of minute size. In addition, much of the orange material concentrated in regular bands about 5 mm. apart. Near the top of the gel an orange-red band one centimetre deep developed. This, of course, was basic lead chromate. Hatschek formed lead chromate in a gel of acid reaction and thus missed the opportunity of making the basic chromate.

Barium carbonate formed in a basic gel containing some sodium carbonate. A silicic acid gel was covered with a solution of a barium salt. The crystalline character of the deposit was not apparent for some time. White spherulites appeared to a depth of about 5 cm., and then flower-shaped crystalline aggregates formed. They were very small, but the crystalline character was apparent to the unaided eye.

Potassium bisulphate crystals of considerable size appeared in a gel formed by the "Hopkins process"[37] of obtaining soluble potassium salts and aluminum sulphate from feldspar. Finely ground feldspar was heated at 300° with moist potassium hydroxide. This partial decomposition of the feldspar was then completed by reaction with sulphuric acid. In commercial practice hydrochloric acid is used at this point. Using sulphuric acid in a mere laboratory experiment, a silicic acid gel formed and crystals of $KHSO_4$ grew in this medium.

Sugar crystals often appear in ordinary fruit jellies. I have a number that measure about 5 × 7 × 9 mm.

Calcium tartrate crystals of great beauty, 20 × 5 × 5 mm., were easily obtained in a U tube containing a 1.06 water-glass-0.5 N acetic acid gel by filling one arm with a solution of calcium chloride and the other with a solution of tartaric acid.

Copper tartrate crystals of perfect shape and clear blue color were made by covering a 1.06 water-glass-3 N tartaric acid gel with 0.5 N copper sulphate.

Zinc-ammonio chloride crystals of several centimetres in length were found in the gelatinous packing next the zinc wall of commercial dry cells. These colorless sheets are of the formula $ZnCl_2.2NH_3$. They were also obtained by Marignac in a Leclanche cell, but not of such large size. The starch paste or other gelatinous filling next the wall of a dry cell regulates the diffusion rates of the zinc chloride and ammonia formed by the chemical action of the battery on discharge, thus greatly aiding crystal development. On short periods of service, with rest intervals, these crystals were longer than in batteries run down by continuous service. This agrees with the time feature of the theory proposed in this paper.

DEVELOPMENT OF A THEORY.

Early in my work I decided that the most important feature of the favorable influence of gels on reactions forming crystals was the capillarity of the gel structure. To test this, I used a layer of finely powdered silica in a U tube, soaked it with water to dislodge air, and filled one arm with a solution of potassium dichromate and the other with a solution of silver nitrate. Slow diffusion of the two salts through the capillary spaces between the silica grains allowed the formation of good crystals of silver dichromate. Later I learned that Dreaper had already developed that idea, using not only a layer of sand, but a single capillary tube. It may be objected that the rather great surface of finely divided silica permits an appreciable solution of silica, thus filling the space pores with a weak gel of silicic acid. Coarse sand did not serve so well.

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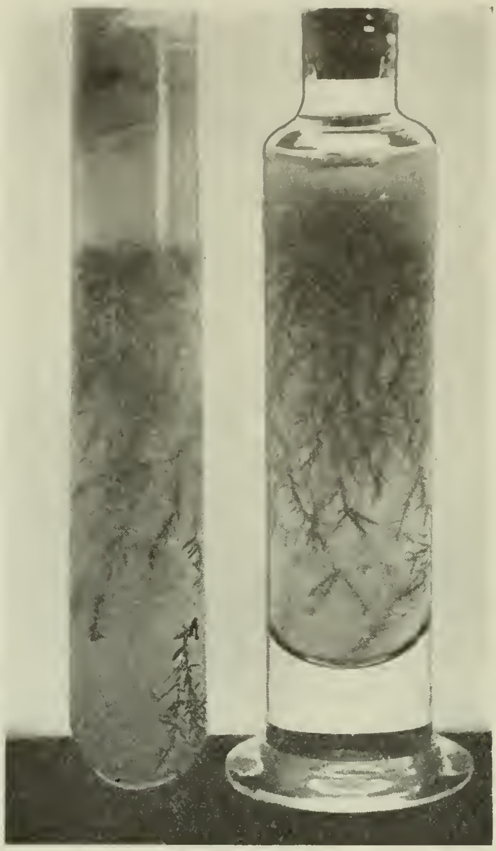
[37] Holland, Frazer, Miller, U. S. Patent 1,196,734.

It seemed worth while to extend somewhat the list of substitutes for gels in this work, so flowers of sulphur was substituted for sand in the above experiment. Some trouble was experienced in packing the sulphur in the bend of the U tube, and many attempts failed from too close packing for free diffusion. A platinum wire was used to dislodge the persistent air bubbles. Finally an excellent band of red crystals of silver dichromate formed where the silver ion met the dichromate ion. Barium sulphate and alundum powder served much better than the sulphur as substitutes for a gel. In fact, the results with alundum were startling. Silver dichromate formed in flat needles one centimetre in length. Closely-packed asbestos gave fair results. Certainly it cannot be urged that any gel was present in the experiments with a membrane of sulphur or alundum or barium sulphate.

Without doubt, any compact mass of insoluble discrete particles with proper sized capillaries will function as a gel in favoring the formation of crystals. Other influences may be present in a true gel. Adsorption, pressure, and solubility effects may greatly influence the capillary space results. A rather amorphous insoluble compound first formed by the meeting of two reacting substances in a relatively narrow channel may so further regulate the rates of diffusion as to give time for crystal formation of more of the same insoluble compound. In this suggestion the geologist may possibly find an explanation of the marked crystalline nature of some mineral veins. The pathologist, too, may obtain some light on the accumulation of crystalline deposits in animal tissue.

To test the theory, the mouth of a small specimen tube was covered with a sheet of goldbeater's skin, holding it on firmly with a rubber band. The tube had first been filled with a solution of 0.1 N potassium iodide. Care was taken to leave no air bubbles on the under side of the membrane and to rinse the outside of the tube. The tube was then immersed in a small beaker of saturated lead acetate solution. At once an almost amorphous precipitate of lead iodide appeared on the under side of the membrane, and in less than a minute crystals of lead iodide fell in a beautiful gleaming shower, rapidly increasing in amount. It is very easy to secure gleaming crystals of lead iodide by cooling its hot solution, but in this experiment the solutions were cold. Mixing the same solutions in a test-tube without the use of a membrane, a yellow powder results.



"Lead trees" in silicic acid gels.

If the more concentrated solution was placed inside the specimen tube, the crystals formed on the upper surface of the membrane. This is in accord with the osmotic difference rule of Pringsheim. With less difference in concentration of the reacting substances solutions the reaction was much slower.

Separating solutions of silver nitrate and potassium dichromate in this way, it was a simple matter to make a gramme or two of brilliant crystals of silver dichromate settling to the bottom of the tube. Possibly this method may be of some use in the preparation of pure compounds, since the crystals are not mixed with an annoying gel. Other thin, semipermeable membranes serve. Parchment paper is good, but goldbeater's skin is most suitable.

In a number of experiments it was observed that at first a rather amorphous or, at least, fine-grained precipitate formed on the surface of the original membrane, thus forming a new membrane of different capillary structure which exerted a marked influence on rates of diffusion. The result of checking the rates of diffusion of the reacting substances was to give time enough for the growth of minute particles to crystalline size.

Barium sulphate is most annoying in quantitative analysis because of its tendency to form in slow settling colloidal suspensions. It seemed an interesting experiment to precipitate it by the diffusion cup method and observe the rate of settling. I believed that if I placed a dilute solution of a sulphate inside the specimen tube, covered it with a goldbeater's skin touching the surface of the solution, and immersed the tube in a more concentrated solution of a barium salt, the barium sulphate formed on the under side of the membrane would be of much larger crystals than usual and would settle rapidly. It did. Some modification of this experiment may possibly be applied to the determination of sulphates.

To carry the theory further, the only need of the goldbeater's skin is to prevent sudden wholesale mixing of the solutions and mechanically sustain the rather amorphous precipitate first formed, which then functions as the real active membrane. This theory is not universal in its application, for in gels excellent crystals of a number of substances formed without the appearance of a preliminary compact layer of precipitate. In these instances only the gel functions in regulating diffusion. The theory does apply, however, in the absence of a gel and in all instances where a compact precipitation band is formed.

John Johnston's method of preparing crystals of increased size by the slow diffusion of two reacting solutions in a large volume of water at two widely separated points supports the theory above given. De Schulten's experiment, described earlier in this paper, is somewhat similar to Johnston's.

The usual gels employed in earlier investigations were agar, gelatine, and silicic acid. To this list I added the insoluble powders above described, and also gels of ferric phosphate and manganese arsenate. Both of these permitted the formation of good crystals of lead iodide, silver dichromate, and mercuric iodide. It is noteworthy that they are inorganic gels like silicic acid. Probably the protective colloid action of organic gels hinders crystal growth.

It is not necessary that this subject be limited to gels. Since the influence of gels on crystal formation is largely that of regulated diffusion, it is permissible to discuss even such structures as steel. Alexander [38] holds that graphite in steel is partly in the colloidal form and therefore inhibits crystallization. It would seem that films of colloidal graphite around crystalline nuclei of cementite, for example, must greatly influence the growth of those crystals when steel is cooled from a high temperature. Colloids in general retard diffusion. But, instead of inhibiting crystallization, as Alexander believes, it is conceivable that, although cementite crystals in the steel may form more slowly, they may be larger and of different shape than if formed rapidly.

Ice-cream without egg-white or gelatine or some other protective colloid is grainy. Of course, the lactalbumin in the milk is a protective colloid, but there is not enough of it. In marshmallows crystallization of the sugar is prevented by the protective colloid effect of gelatine or gum arabic.

The reduction of gold or copper salts in plastic glass with the production of a ruby tint is somewhat related to this topic. Possibly new ornamental effects could be obtained by experimenting with diffusion zones while the glass is hot enough to be plastic. Of course, the glass in that condition is not a gel, but it permits slow diffusion.

There seems no good reason why many very viscous substances should not function as gels in their influence on diffusion reactions.

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[38] *J. Soc. Chem., Ind.*, **28**, 280.

SUMMARY.

1. Good crystals of silver dichromate were obtained by allowing the slow diffusion of solutions of silver nitrate and potassium dichromate through flowers of sulphur. Barium sulphate powder served as well, and alundum was even better. This confirms Dreaper's opinion that diffusion through capillary spaces other than those in a gel may be efficient in aiding crystal formation.

2. An experiment was devised to prove that in many instances the amorphous or fine-grained precipitate formed when two solutions meet acts as a membrane or network of capillaries, retarding further diffusion and favoring the formation of more of the precipitate in larger crystalline particles.

3. Silicic acid gels of alkaline reaction were made by mixing sodium silicate with less than enough acid for neutralization. These basic gels made possible the production of crystalline salts not possible in a gel of acid reaction.

4. Gold in a beautifully crystalline condition was best prepared by mixing equal volumes of a water-glass, 1.06 density, and 3 N sulphuric acid, adding 1 c.c. of 1 per cent. chloride to 25 c.c. of the mixture and, after solidification of the gel, covering with a solution of 8 per cent. oxalic acid.

Startling rainbow bands of red, blue, and green colloidal gold, mixed with scattered crystals, resulted when the water-glass was 1.16 density. Both methods worked readily and gave better results than any yet recorded.

5. Perfect tetrahedrons of copper were secured by using 1 per cent. hydroxylamine hydrochloride to reduce dilute copper sulphate in a silicic acid gel. Peculiar aggregates of tetrahedrons similar to those found in copper deposits in Nature were also observed.

All the steps of the reduction of cupric hydroxide to yellow and red forms of cuprous oxide were shown simultaneously in a series of many bands, using glucose as the reducing agent in a silicic acid gel of alkaline reaction. With 1 per cent. hydroxylamine the same reduction was carried through the cupric hydroxide and cuprous oxide to tetrahedrons of metallic copper. This suggests a method of controlling the different steps of other reactions for study.

6. Lead iodide in perfect hexagonal plates, 5 mm. wide, and

golden, fern-like growths, 8 cm. long, were formed in silicic acid gels. A basic lead iodide in yellow-white needles, 2 cm. long, formed by the action of excess lead acetate on potassium iodide in a slightly acid gel and even better in a slightly basic gel. Iodine was released on the surface of crystals of lead iodide, as shown by the presence of a little starch mixed with the silicic acid. Some reduction of lead iodide must have taken place, possibly caused by the starch.

7. Red mercuric iodide in 2 cm. needles or, in smaller crystals, banding in as many as forty regular bands in a distance of 8 cm. was obtained by the diffusion of a mercuric chloride solution into a silicic acid gel containing potassium iodide. With certain concentration conditions yellow crystals formed in front of the red needles and were finally changed into the red mercuric iodide. Soluble chlorides exerted a striking influence on the size, form, and arrangement of the mercuric chloride crystals.

8. Magnificent red-black crystals of a basic mercuric chloride resulted when a saturated solution of mercuric chloride diffused into a silicic acid gel of slightly basic reaction. In a very slightly basic gel these crystals were grouped in a remarkable series of bands. The presence of a little glucose exerted a marked influence, changing the color and developing over one hundred compact bands in a distance of 8 cm.

9. Silver sulphate crystals appeared in less than one hour when N silver nitrate diffused into a silicic acid gel made by mixing equal volumes of 1.06 density water-glass and 3 N sulphuric acid. In a few days orthorhombic slabs, 3 cm. long, developed If enough potassium dichromate to make the whole gel 0.1 N molar with respect to this salt only was present, the long slabs were a beautiful clear red. In the presence of excess silver nitrate near the surface of the gel silver chromate was formed, and, since silver chromate and silver sulphate are isomorphous, red mixed crystals resulted. The color of the crystals was made any depth of red by varying the concentration of the potassium dichromate in the gel. Farther below the surface of the gel the silver nitrate became less concentrated, and triclinic crystals of the red-black silver dichromate appeared. In time they grew to a size 5 × 5 × 1 mm.

10. Silver acetate grew in gleaming white sheets, 2 cm. long, when N silver nitrate diffused into a silicic acid gel made from

water-glass and acetic acid. These crystals appeared in a few minutes. Such protective colloids as gum tragacanth, when present in very small amounts, twisted the straight crystals of silver acetate into fantastic shapes.

11. Basic lead chromate was made in crystalline bands by diffusion of lead acetate solution into a silicic acid gel of alkaline reaction containing potassium chromate; urea nitrate in large crystals, by the diffusion of nitric acid into a silicic acid gel containing urea; perfect crystals, 5 mm. wide, of acid potassium tartrate and perfect crystals of copper tartrate in a silicic acid gel made with tartaric acid; and monosodium phosphate in large, colorless rhombohedrons by mixing disodium phosphate in a sodium silicate-acetic acid gel.

12. Dry batteries discharging for short intervals developed colorless slabs, several centimetres in length, of $ZnCl_2.2NH_3$ next the zinc wall of the container. The gelatinous paste in this part of the cell caused slow diffusion of the zinc chloride, and ammonia formed by the discharge of the cell.

OBERLIN COLLEGE, OBERLIN, OHIO,
July 26, 1917.

Farm Weirs. (*U. S. Department of Agriculture,* Farmers' Bulletin No. 313.)—The value of water has increased in the arid lands of the West with the development of the country to a point where there is now a general demand for accurate devices for the measurement of small streams of flowing water. A "weir" is one of the most commonly used devices for this purpose, and the best known are the rectangular, the Cipolletti, and the 90-degree triangular notch types with free fall, sharp chests, and full contractions. Discharge formulæ for these types are given and are so arranged that if the "head" or depth of water flowing over the weir notch is known, the flow by cubic feet per second can be readily ascertained. A table of hydraulic equivalents enables this flow to be changed into miner's inches or statute inches.

Casting Shells in Permanent Moulds. E. A. CUSTER. (*Proceedings of the American Foundrymen's Association,* September 25–28, 1917.)—One of the remarkable changes that the present conflict has brought about is the spectacle of raining upon the enemy an unheard-of number of high-calibre cast-iron shells. There is nothing new in the use of cast-iron projectiles—before this age of steel they were the sole means of battering down defences and attacking at long range. Some of the reasons why the use of cast-iron shells was abandoned are that the metal has never made a very good record for uniformity, freedom from sponginess and gas-holes; its tensile strength is low, and it lacks toughness. Any of the defects commonly found in cast iron will seriously affect the trajectory and direction of a shell and render it comparatively useless. If one portion is spongy, and hence lighter than the remainder, it will wobble in its flight and its main purpose will be destroyed. The weakening effect of sponginess or blowholes may cause the shell to break under the impulse of discharge and destroy the gun. A forged steel projectile meets all these objections, and for that reason has been universally adopted.

As early as May, 1913, German and Italian munition makers were discussing the manufacture of cast-iron projectiles. In August, 1913, it was reported that shells had been made that were satisfactory, in that they had the proper degree of fragmentation and were strong enough to resist the effect of the propelling charge. These shells were made in iron moulds with iron cores. Their peculiarly destructive effect was later observed in the field, not only in the open, but also against earthworks, and the then prevalent idea that the German forces were using cast-iron shells on account of the scarcity of steel was abandoned.

Target shells have been made of cast-iron for many years, and almost any foundry can make them. The foundry requirements for this work are described in the April, 1917, issue of *The Foundry* by Edgar A. Custer, Jr., and the methods of melting and the care of iron and fuel that must be observed, whether the shells are made in sand or in a permanent mould, are there set forth. Ordinary foundry iron, when properly cast in a permanent mould and when removed at the proper time, has in the resultant casting the same degree of hardness, irrespective of any variation in the chemical constituents, so long as the same size, weight, and shape of casting is made. The time the casting remains in the mould is the determining factor. A casting weighing about 60 pounds remains in the mould 4 or 5 seconds, while a casting of the same general contour weighing 500 pounds will require 25 to 60 seconds before it is safe to lift out.

The low cost and great output per day and effectiveness of cast-iron shells have been so completely recognized that two of the warring nations are using them to an enormous extent. France is casting them in sand, and Germany, from the best information available, is casting them in permanent moulds. A steel forging for a 4.7-inch shell costs over $7 at the present writing, while a casting of the same shell can be made for a little over $2. Furthermore, a liberal saving in labor and machine-tool consumption can be effected. When larger projectiles are made, a larger proportionate saving will follow. When more than 1,000,000 rounds per day are made—and this is a low figure to expect—the difference in cost seems incredible.

ON THE NATURE OF THE ORDINARY GASEOUS ION.*

BY

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The assumption that the ordinary gaseous ions consisted of clusters of from 6 to 30 molecules surrounding a unit electrical charge was made to explain the fact that the diffusion coefficient of an ion into a gas is from one-fifth to one-tenth as great as the diffusion coefficient of a similar uncharged molecule into the same gas. This assumption has up to the present been accepted as giving the correct explanation of this fact, as well as of the behavior of ions in general. Recent experiments on the mobilities of the ions at low pressures by Wellisch,[1] and on the mobilities of ions in high electric fields by the author,[2] as well as the proof by Franck,[3] Haines,[5] and Franck and Pohl[4] of the existence of "free electrons" as carriers in various gases, have thrown serious doubt upon the correctness of such a theory. An alternative theory was proposed in 1909 by Wellisch[6] and Sutherland[7] which assumed the ions to be single charged molecules. The lowering of the diffusion coefficients was ascribed to an increased drag on the ions in the gas due to their attractive forces on other molecules. In view of the apparent failure of the cluster theory in the light of the newer results it is of importance to study the latter, or "small ion," theory with reference to these phenomena, and to compare the explanations of the various other phenomena which it yields with those of the cluster theory, to see if they are equally satisfactory. It is with this object in view that this paper is written.

It will be generally conceded that modern results all point to the view that atoms of matter are electrical in nature. It is not strange, then, that electrical charges on molecules will exert attractive forces on other neutral molecules. The difference in the two theories as to the nature of the ions lies in the nature of the laws of attraction between the ion and the surrounding molecules. On the cluster theory the force must be very intense when the charge is within one or two molecular radii from the surface of the molecules attracted. It must, however, rapidly diminish to negligible dimensions with increasing distances between the charges and the molecules. In the case of the small ion theory the forces must be comparatively weak even with distances comparable to the molecular diameters between the charges and the molecules. It must never reach such dimensions that the attracted molecules are able to adhere to the surface of the ion under the values of the kinetic energies of impact of gas molecules at ordinary temperatures. The forces must, however, extend with appreciable values over distances large enough to make the apparent size of charged molecules large in comparison to the size of the uncharged molecules. A definite decision as to the validity of one theory to the exclusion of the other would very definitely decide what sort of forces are acting between charges and molecules.

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* Communicated by the Author.

The ions have been most thoroughly studied through the measurement of their mobilities, which may be fairly accurately determined by a number of different methods. The mobility is defined as the velocity of the ion in centimetres per second for an electrical field of strength of one volt per centimetre. This property of the ions is closely connected with the diffusion coefficient to which it is related by means of the equation $U = DP/Ne$, where U is the mobility, D is the diffusion coefficient, P is the pressure, N the number of molecules in a unit volume of the gas, and e the value of the electron.

Before * proceeding further with the study of the effect of the various factors influencing the mobilities, it is necessary to make a few comments concerning the methods used in determining mobilities. There are two facts common to all methods of mobility measurement which, as it seems to the author, have not been given the prominence they possibly deserve. The first fact is that in all the usual devices for measuring the mobilities of the ions these mobilities are measured for ions comparatively freshly generated. The importance of this becomes evident when one realizes that under these conditions the mobilities of the ions are determined on ions which may not be in equilibrium with their surroundings. The second fact is that all the measure-

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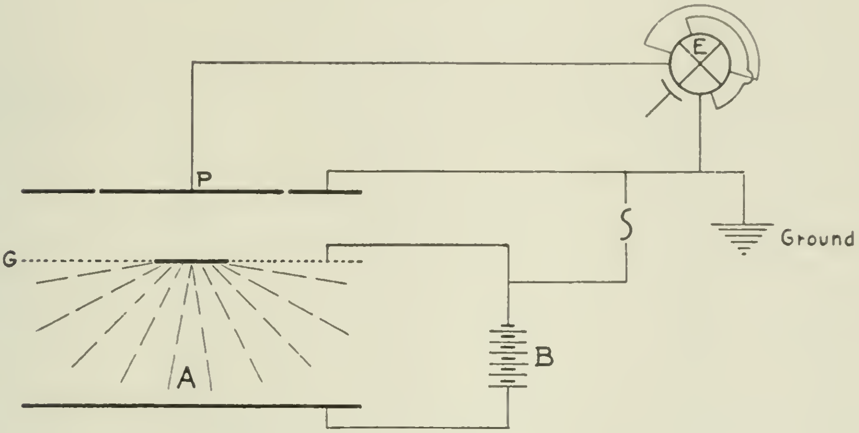
* The explanation of the difference in mobilities of the positive and negative ions and the other phenomena set forth in the following section is still somewhat tentative.

ments give, not the mobilities of single ions, but the mean mobilities of large groups of ions. Thus a small fraction of ions which have not yet reached equilibrium would change the value of the mean appreciably, so that conclusions based on it might be erroneous. As it is to be shown that just such actions taken together with the theory of the small ion might enable one to explain a number of the ion phenomena without recourse to the questionable cluster theory, it is important that these actions be clearly brought out. For the sake of simplicity the Rutherford alternating-current method of determining mobilities as modified by Franck[8] will be used as a typical example.*

In that method the ions generated by the alpha particles of

FIG. 1.



some radio-active substance on the disk ionize the air in the chamber *A*, Fig. 1. The ions to be used are then driven through the meshes of the metal gauze *G* by means of a small accelerating field supplied by the battery *B*. Above *G* is placed a plate *P* which can be connected to an electrometer. The distance to this plate is generally accurately known and kept constant. Between the plate *P* and the gauze the alternating potential is applied. The frequency of this is in general kept constant, and the potential is varied in making the determinations. The method usually employed is to change the potential of the alternating field and record the values of the ionic currents to the plate *P*, as shown by electrometer deflections. These currents are then plotted against the potential of the alternating field. If the apparatus be assumed to be ideal, and if the secondary factors to be discussed are assumed to be absent, the curve will take the following form (Fig. 2): Starting with the low potentials, there will be no deflections of the electrometer, or at best small ones, which will be constant, independent of the value of the potential. At a certain critical potential V_0, at which the ions are just able to traverse the distance between the plates in the time of a half period, the current will suddenly rise parallel to the axis of abscissæ. This reaches a certain maximum value, and from then on the current gradually increases with the potential. It is the value of V_0 taken from the curve which, if substituted in a simple formula with the period of alternation of the current and the plate distance, will give the value of the mobility. In practice the ideal case is never realized, for the meshes of the gauze have a finite depth and the ions do not all start from the same level in the meshes. The diffusion of the ions through the gauze would also act to prevent this condition from being realized. The plates are, furthermore, never exactly parallel, and this factor, as well as any irregularity in the field between the gauze and the plate, enhance the deviations. The result is that the

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* This method is used for the sake of simplicity. It looks at first sight as if the Zeleny[44] method which measures the slower ions of a given group would not be subject to the same deviations. It will be seen, on closer scrutiny, that in this case also an appreciable number of ions of changing mobility, due to lack of equilibrium, will influence the curve yielding the critical voltage in a similar manner to that in which these curves are altered in the Rutherford method. The final value of the mobility thus obtained will be about the same.

FIG. 2.

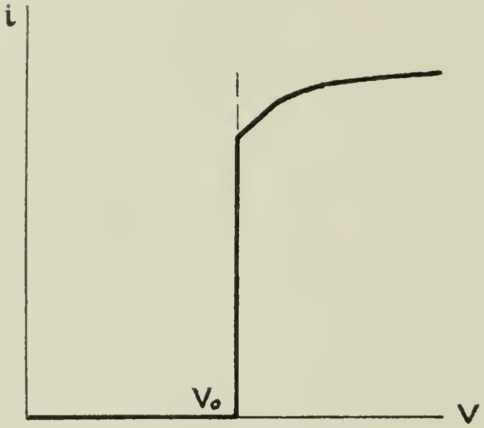
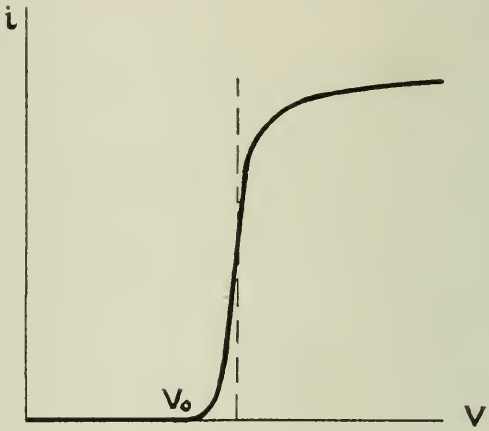


FIG. 3.



rise of the ion current at V_0, instead of being vertical, becomes inclined to the vertical (Fig. 3). The *point* transitions (*i.e.*, discontinuities) from the horizontal elements of the curve to the vertical element also disappear, and the transition leads to a smooth curve which loses its sharpness more and more the greater these effects. These so-called instrumental errors, when reduced to a minimum, are not of themselves serious, as they act symmetrically. When, however, superposed upon errors due to the agents above mentioned, they may well change the results of the measurements.

The process of ionization consists in the removal of an electron from a neutral molecule, the molecule thus acquiring a resultant positive charge, and on the small ion theory becoming a positive ion. The space below the gauze C is accordingly filled by the ionizing agent with a number of these ions and with free electrons. The negative carriers in all gases at high pressures, except the inert gases, consist, for the most part, of carriers with approximately the same mobility as the positive ions. Consequently, whether clustering takes place or not, in order to have their mobilities measured as ions the negative carriers must change from electrons to ions initially by union with a neutral molecule. It is permissible to suppose that the molecule and the electron must meet in some fortuitous manner in order that they may unite to form an ion such that every encounter between electron and ion will not necessarily mean ion formation. Let it be assumed that it is possible for an electron to traverse a great many mean free paths without uniting to form an ion. Since the electrons start toward the gauze as soon as generated, and since the mobility of the electron is very high, it is possible that a number of the electrons get through the gauze in the free state. Those electrons getting through the gauze will then come under the influence of the alternating field. Some of them will succeed in traversing the space from G to P without uniting with a molecule. The effect of these electrons will be to give an initial current from the plate to the gauze at values of V way below V_0. Most of the electrons penetrating the gauze will combine with molecules before reaching P. The ions formed between G and P will consequently reach P at values of the voltage V *below* V_0, which is necessary for the slow normal ions. Since the number of electrons covering a given distance in the gas without union follows a probability law, the curve between ion current and voltage from the lower values of V to V_0 will increase according to such a law. Thus the lower corner of the ideal mobility curve would be rounded by this curve (Fig. 4). Such a curve superposed on the curve distorted by the instrumental errors could materially affect the value of V chosen as V_0. The effect of such distortion on V_0 would tend to give too small values for it. Thus the mobilities calculated from such a V_0 would be higher than the *real* mobilities of the negative ions. Since the positive ions have no chance for such a distortion, it is possible that in this action one has an explanation of the difference in mobility of the positive and negative ions. It is to be noted that the gases in which the electrons have been shown to be free for greater periods of time are the gases that exhibit the greatest differences between the mobilities of the positive and negative ions; *e.g.*, N_2, H_2, air, pure He and Ar, compared to CO_2, CO, NH_3, C_2H_5OH. If such an action taking place to the slight extent which it does is able to produce appreciable changes in the mobilities of the ions in some of the gases at ordinary pressures, it is not in the least surprising that certain gases at low pressures might give quite abnormally high values of the *negative mobility only*. Such mobilities at low pressures were originally taken as evidence for a disintegrating cluster ion.

FIG. 4.

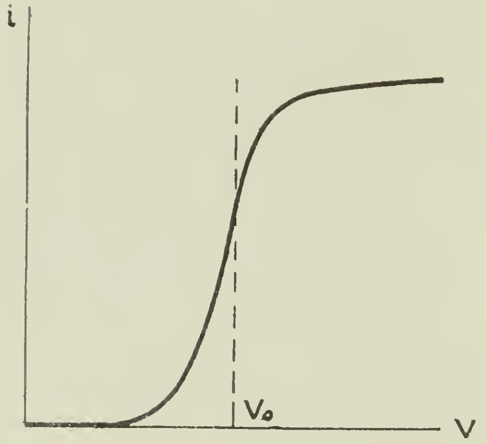
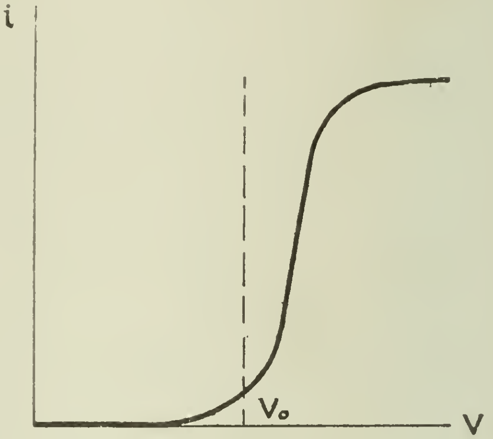


FIG. 5.



Again, the following actions might be imagined as taking place. Let it be assumed that the gas contains an easily condensible vapor of a pronounced electronegative character and having a high dielectric constant, such, for instance, as alcohol or water vapor. According to Barus,[9] there is evidence that such vapors contain, besides the single molecules, an assortment of groups of molecules, or nucleii, of various sizes. It is on these nucleii that condensation takes place in dust- and ion-free air containing water vapor when eight-fold supersaturation is reached. If such vapors are present in a gas, there will always be a number of such nucleii present per cubic centimetre which will increase as the concentration of the vapor is increased. At low concentration these nucleii would be too few in number to exert much effect. The presence of electronegative molecules alone would tend to decrease the number of *electrons* reaching the gauze in the free state. By an electronegative gas is meant one which shows a tendency to take up negative charges. This is analogous to the use of the term "electronegative" applied to the chemical elements which in chemical combination tend to assume the negative charge where possible. In general, gases which act strongly electronegatively in their chemical reactions will also have a high electron affinity in the molecular gaseous state. In such a gas the encounters between neutral molecules and electrons will more frequently result in ion formation because of the nature of the vapor. The first effect of the presence of such vapors would then be to tend to wipe out the difference in the mobilities between the positive and negative ions by preventing the distortion of the curves through premature negative charges. On increasing the vapor concentration the number of nucleii would increase to such an extent that it would be possible for normal negative or positive ions to encounter appreciable numbers of these between the plate and gauze. The probability of such an encounter is still further increased because of size and high dielectric constants of these nucleii. An ion caught by such a bulky nucleus would never reach the plate P at the value of V_0 for the normal ions. At higher values of V than the true value of V_0, some of these retarded ions will reach the plate and contribute to the current from G to P. The greater V above V_0, the greater the effect of these will become. This abnormal increase of current above V_0 superposed on the instrumental errors will distort the curve in such a manner (*i.e.*, by causing the upper horizontal portion of the curve to slope upwards) that the values chosen for V_0 for the ions will be too great (Fig. 5). The mobilities of both ions will accordingly appear to decrease with increasing concentrations of the vapors, the values of the negative mobilities decreasing more rapidly than the positive ions—a phenomenon that is actually observed.

Having discussed the effect of certain of the more obscure aspects of the methods of ion measurement, to which reference will repeatedly be made in what follows, one may now turn to the discussion of the ion theories.

1. *Mobility and the Dimensions of the Carrier.*

Except for the case of electrons, the nature of the initial carrier of the charge appears to make little or no difference on the mobility of the carrier. For example, methyl iodide ions in an atmosphere of hydrogen were shown by Wellisch[10] to have the same mobilities as the hydrogen ions. The same holds true for the recoil atoms from radio-active changes, as shown by Rutherford,[11] Franck,[12] and Franck and Meitner.[13] Such results would be predicated on the cluster theory, since the cluster would completely change the original carrier. It would, however, only be possible if a sort of compensating action were supposed to take place between the mass or size of the nucleus and the number of molecules entering into the cluster. This action would assume a decrease of the attracting force on outside molecules of the cluster with increasing dimensions of the nucleus, thus limiting the number of attendant cluster molecules. This assumption does not seem unnatural. On the small ion theory the explanation would be similar, except that in this case the compensating action would take place between the dimensions of the nucleus and the magnitude of the attractive forces on outside molecules, which would *not* involve the formation of a cluster. The increased size of a charged molecule would act to compensate the increase of the mobility due to the decreased drag on outside molecules with a large body to the ion. Accordingly there is no choice between the theories as regards this action.

2. *The Nature of the Surrounding Gas and the Mobilities.*

The action of the nature of the surrounding gas on the mobilities seems to be influenced by several distinct properties of the gas. These, in general, are superposed, and in studying the question it is first necessary to separate them clearly. The properties of the gas active in this respect are: (1) The molecular weight of the molecules; (2) the dielectric nature of the gas; (3) the electrochemical nature of the gas. It might also be expected that the radii of the gas molecules might be active.

The effect of the electrochemical nature of the gas must be discussed first, as it masks the other factors mentioned. The ratio of the negative to the positive mobilities of the ions in a given gas (*i.e.*, U−/.U+) appears to be greater than unity in all the more electropositive gases. It has never unquestionably been shown beyond the limits of experimental error to be less than unity for any gases.* The assumption will be made at this point that the mobility of the negative ion is never less than that of the positive ion. This means that the normal mobility of ions in a gas is given by the positive ions. It further means that in case the mobilities of the ions differ in the more positive gases, it is the negative ions that for some reasons appear to have abnormally high mobilities. This abnormal mobility of the negative ion in electropositive gases, *i.e.*, gases that tend to lose electrons rather than gain them, has already been explained, in the discussion of the methods of mobility measurements, on the assumption that the electrons, when newly generated, do not unite to form ions with every molecular impact they make. If this view is not accepted, it forces one to assume that the difference of the mobilities is due to the fact that the force of dielectric attraction acting on a group of electropositive molecules is greater for a positive than for a negative charge.† In other words, the dielectric constant varies with the sign of the charge, and this variation is different for different gases. This is an assumption that the writer is loath to make.

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*In the results of Wellisch[14] this ratio is about 0.8 for ethyl alcohol vapor, while it is greater than unity in the results of Przibram,[14, 45] and in later results by Wellisch.[46] With this exception, the cases where the ratio of the mobilities is less than unity all lie pretty well within the limits of experimental error. In general the ratios in the electronegative vapors approach unity.

†In a recent brilliant paper[46] Wellisch explains the difference in the mobilities of the positive and the negative ions on the basis of differences in the elasticity of the impacts between negative ions and various neutral molecules. Such differences in the natures of impacts of electrons with different types of molecules were actually observed by Franck and Hertz.[47] It seems to the writer that this is probably the most fruitful explanation of this difference yet proposed.

Turning now to the other factors, one may make use of the assumption that the mobilities of the positive ions are the normal mobilities of the gaseous ions. With this assumption, the variation of the mobilities with the molecular weight of the gases may be studied. Kaufmann[15] pointed out that if the mobilities of the ion in the so-called "permanent gases" (*i.e.*, helium, nitrogen, oxygen, and carbon dioxide) be taken, the mobilities appear to be approximately proportional to the inverse square roots of the molecular weights of the gases. For the vapors and for most other gases this law does not seem to hold, as may be seen from Table I, fifth column, where $U_H/.U_A$ is divided by $(M_A/M_H)^{\frac{1}{2}}$. The resulting figures are not even approximately constant. It was noticed by the writer, in testing this law, that the greatest deviations from constancy occurred for gases having the greatest dielectric constants. The value of the dielectric constant for the gases diminished by 1 was then determined for these gases and included in the table. It is seen that if one divides the

TABLE I.

Gas	$\overset{U^*}{+}$	$\frac{U_H}{U_A}$	$\left(\frac{M_A}{M_H}\right)^{1/2}$	$\frac{\left(\frac{U_H}{U_A}\right)}{\left(\frac{M_A}{M_H}\right)^{1/2}}$	$(K-1)$	$(K-1)$ Rel. to H_2	$(K-1)^{1/4}$ Rel. to H_2	$\frac{\frac{U_H}{U_A}/\left(\frac{M_A}{M_H}\right)^{1/2}}{(K-1)^{1/4}}$ Rel val.	Observer
Hydrogen[14].......	6.02	1	1	1	.000273	1	1	1	Franck.
Helium...........	5.09	1.186	1.42	0.836	.000074	.271	.728	1.15	Franck.
Argon............	1.37	4.405	4.47	0.986	.000100	.366	.775	1.27	Franck.
Nitrogen.........	1.27	4.755	3.74	1.272	.000590	2.16	1.210	1.05	Franck.
Oxygen..........	1.30	4.64	4.00	1.158	.000540	1.98	1.180	.98	Franck.
Air..............	1.35	4.47	3.87	1.155	.000590	2.16	1.210	.96	Mean.
Ammonia.........	0.74	8.17	2.92	2.795	.007700	28.18	2.310	1.21	Wellisch.
Carbon dioxide...	0.81	7.46	4.69	1.606	.000960	3.51	1.370	1.17	Wellisch (also mean)
Carbon monoxide–	1.10	5.49	3.74	1.466	.000690	2.53	1.260	1.16	Wellisch.
Sulfur dioxide.....	0.44	13.72	5.66	2.425	.009050	32.96	2.400	1.01	Wellisch.
Nitrous oxide.....	0.82	7.37	4.69	1.570	.001070	3.92	1.410	1.11	Wellisch.
Ethyl alcohol.....	0.34	17.75	4.80	3.697	.009400	34.41	2.430	1.52	Wellisch.
Carbon tetrachloride........	0.30	20.01	8.78	2.280	.004260	15.60	1.990	1.15	Wellisch.
Ethyl chloride....	0.33	18.3	5.67	3.228	.015500	56.80	2.750	1.17	Wellisch.
Ethyl ether.......	0.29	20.8	6.08	3.422	.007420	25.62	2.240	1.53	Wellisch.
Methyl bromide...	0.29	20.8	6.88	3.024	.014600†	53.46	2.710	1.11	Wellisch.
Ethyl formate....	0.30	20.01	6.08	3.292	.008700	31.87	2.380	1.38	Wellisch.

†Ethyl bromide. Mean 1.18

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* The values of the positive mobilities used in the table are chiefly those of Franck[14] and Wellisch.[6] Those obtained for a large number of vapors by Przibram[45, 14] are not used in this table, since they were determined by a method the results of which are somewhat unreliable. Przibram[45] himself was forced to alter the original values which he published by a considerable factor in a later paper, due to the inaccuracies of the method.

ratio above by the fourth root of the dielectric constant less one relative to hydrogen, one obtains values of the whole ratio that are very nearly constant and equal to unity. This holds over a wide range of compounds. There are a few variations of as much as 30 per cent. from the mean. However, when it is considered that with possible errors of as much as 15 per cent. in the mobilities, and with possible errors of 50 per cent. in the dielectric constants due to the differences in temperature for some of the easily condensible vapors, it is not strange that the agreement is not more perfect. One must conclude, then, that the Kaufmann law holds fairly well, provided the variations of the dielectric constant are allowed for.

One might expect that the mobility would vary as some function of the radius of the molecules in a gas. This does not seem to be the case. In fact, no correlation between various functions of the molecular radii as given by kinetic theory could be found by the writer. This does not seem surprising, as in the case of the uncharged molecules the radius is defined as the mean distance between the molecular centres in collision. What this would amount to in the case of the neutral molecule and the charged ion no one can say. There is no question but that such a radius would depend on the natures of the forces acting on the molecule and the ion; *i.e.,* possibly on the dielectric constant of the molecule, if such a term may be used. The molecular radius is also related in some way to the molecular weight. At any rate, the effect of the radius of the molecules of the gas, or any simple function of this, seems to be absent as an active factor in influencing mobilities.

The relations above give the essential factors of the variation of the mobility with the nature of the gases; *i.e.,* from gas to gas. This variation is superposed on the total abnormal lowering of the diffusion coefficients below that of neutral molecules. Even in the case of positive *helium* ions does one get a positive diffusion coefficient of *considerably lower value* than the diffusion coefficient of neutral atoms of helium. In this extreme case the atoms are small and the value of (K-1) the lowest of that of any gas. Finally, helium has no valency, is inert chemically, and has apparently very little cohesion. There accordingly must be some agent at work which causes the *initial lowering* for *all atoms* and *molecules.* The effect of the other factors would be superposed on this. If this superposed effect be removed, an initial lowering which is the same for all atoms and molecules should appear. This becomes clear in Table II. In this table the diffusion coefficients are given as calculated from the formula $D = 300\ U\ P/Ne$, or very nearly $D = .0236\ U$. Besides this, the table includes the values of the diffusion coefficients of the *neutral molecules* as actually determined for some gases into gases of equal molecular weight. In one case the diffusion coefficient is estimated for these molecules. It may be seen that the values of the ratio of the diffusion coefficients for the molecules to that of the ions range from four to thirteen. It can be further seen that here, as before, the highest values of these ratios lie with the gases that have the highest values of (K-1). If one divides the relative values of the ratios by the fourth root of (K-1), as was done for the mobilities, one finds that this ratio is reduced to a fairly constant value; *i.e.*, about 5.3. The greater variations from constancy observed here are due to the fact that the diffusion coefficients of the molecules into molecules of the same kind could not be used. Approximations had to be made, and it was assumed that, for instance, the value of D for C_2H_5OH into CO_2 was the same as for C_2H_5OH into C_2H_5OH vapor, a wild assumption at best. In the table allowance was made, as far as possible, for the variation in molecular

TABLE II.

Gas diffusing	Gas diffused into	D molecules	U +	D + for ions	D ions actually measured	Relative D molecules / D ions	(K-1) ¼ relative to H_2	D mols. / D ions / (K-1) relative to H_2
Argon	Helium	.706	5.09	1.20	....	5.88 **	.0728	8.10 **
H_2	Nitrogen	.739	6.02	.143	.123	5.16 6.01	....	5.16 6.01
Air	Oxygen	.178	1.35	.0319	.028	5.58 6.36	1.18	4.73 5.38
O_2	N_2	.171	1.27	.0299	.025	5.72 6.85	1.21	4.73 5.68
CO_2	N_2O	(1.5–1.0)	.82	.0193	.*023	0.772 6.52	1.37§ 1.41	5.73 4.76 5.47 4.73
CO_2	CO	1.31	.81	.0193	....	6.80	1.37	4.96 ....
C_2H_5OH	CO_2	.0693	.34	.00805	....	8.50 ...	2.43	3.49 ....
Air	Ethyl acetate	.093	.30†	.0071	....	13.1 ...	2.38	5.51 ....
H_2O	Air	.246	1.35	.0319	....	7.72 ...	1.18	6.53 ....
NH_3	NH_3	.190‡	.74	.0174	....	10.9 ...	2.31	4.72 ....
							Mean	5.3

* For CO_2 into CO_2.
† For ethyl formate.
‡ Estimated.
§ For CO_2 and also for N_2O.
**Values from actual observed values of D ions.

weight, but no allowance was made for the shape of the molecules; *i.e.*, whether they were di- tri-, or polyatomic. It can be concluded from this that an initial lowering of about fivefold in the coefficients may really exist.

The Kaufmann law could be expected to hold equally well on either theory. The action of the value of K-1 in influencing mobilities would also be expected on either theory. The fact that it is the fourth root of K-1 that enters into the Kaufmann law as a correction seems to favor the small ion theory to a slight extent. Nearly all of the cluster theories contain the value of K-1 to the first power as a factor. This, as will be seen later if coupled with an inverse fifth power law of force between the molecules and charges, inevitably leads to a very stable cluster. Consequently the smaller factor obtained above might indicate the existence of a weaker law of force. The general abnormal lowering of the diffusion coefficients of the ions is the original phenomenon which called for an explanation by means of one or the other of the theories. The absence of any dependence of the mobilities on molecular diameters as determined by kinetic theory would have no meaning. The difference between the positive and the negative mobilities in certain gases offers no difficulty to either theory on the explanation given above, unless the reluctance of electrons to unite with molecules to form an ion at first encounter be considered an argument against the cluster theory (see later).

3. *Gaseous Mixtures.*

The influence of mixtures of gases on the mobilities has been but very little studied, with the result that the explanation of the behavior of the ions in mixtures has not lent itself to treatment by any of the mathematical theories yet deduced. The mobilities in mixtures seem to show three different types of deviation from the mobilities in pure gases. Franck and Pohl [3, 4] found that the mobilities of the negative carriers in pure helium and argon were of the order of magnitude of 200 or more. This high mobility of the negative carriers was explained by the assumption that they were electrons which were not attached to atoms. They further found that when small traces of the more electronegative gases were added to the inert gases the mobilities of the negative carriers rapidly fell to the values observed for the positive ions. This may be explained by the assumption that the electrons which were not able to attach to the molecules of the inert gases promptly attached themselves to the molecules of the impurities added, thus forming negative carriers of the dimensions of the normal ions. The greater the concentrations of the impurities, the greater the number of ionic negative carriers formed, and the more nearly normal the negative mobilities will appear.

As an example of the second sort of change produced in the mobilities of the ions on mixing the gases, one may quote the following results taken from a paper by Wellisch [10] as being typical: SO_2 and O_2 were mixed such that the partial pressures were 131 mm. and 629 mm. respectively. The mobilities were measured in this mixture and found to be $u+=0.72$ and $u-=0.76$, while the mobilities in pure SO_2 were $u+=0.44$ and $u-=0.44$, and in O_2 were $u+=1.36$ and $u-=1.78$. In other words, the mobilities seem to take on values intermediate between the mobilities in the pure gases. The lowering of the mobility is greater than would be expected on the assumption that the mobilities followed the simple law of mixtures. No data have been taken for a variety of different concentrations of the same two gases, and so no accurate conclusions can be drawn as to the relations between mobilities in mixtures of gases and the relative concentrations.

The abnormal changes in the mobilities of the ions caused by the addition of small quantities of certain of the very electronegative vapors exhibit a third effect of mixing the gases on mobilities. A striking example of this effect may be seen in the following results.[10] The mobilities were measured in air at atmospheric pressure with an added pressure of

	$U+$	$U-$
6 mm. C_2H_5Br gave	1.37	1.80
6 mm. CH_3I gave	1.37	1.80
10 mm. C_2H_5OH gave	0.91	1.10
9 mm. C_3H_6O gave	1.15	1.37
.... nothing gave	1.37	1.80

These substances are all vapors. The lower two which exert the abnormal effect on the mobilities are substances of pronounced electronegative character that have high dielectric constants in the liquid state and that are also highly associated in that state. Water vapor also belongs to this class.

The first class of lowering discussed is independent of any theory of the ions. On either theory the electron must first add onto at least one molecule before it becomes an ion, which is all that is needed to explain the effects observed. The discussion of the existence of unattached electrons in general will be left to a later topic. The normal change of the mobilities due to mixing two gases is equally well explained by either theory. In the case of the cluster theory, either the size and the composition of the ion may change with changing relative concentrations, or the composition of the cluster may stay fixed and the effect of changing the mixture could be caused by a change in the properties of the surrounding gas molecules which do not enter into the cluster. It seems quite likely that both of these effects are of importance, for the latter effect alone might lead one to expect the simple law of mixtures to hold. On the small ion theory the effect of an altered cluster is substituted by a change in drag on the small ion by changes in the natures of the surrounding gas molecules. The third type of change in mobilities caused by small traces of certain of the negative vapors can be explained by assuming that, due to the powerful associative tendencies of these vapors, the Barus nucleii are present in appreciable quantities. These would have the effect on the mobilities due to the peculiarities of the methods of measurement which have been already discussed. This explanation applies equally well to the cluster and the small ion theories. Aside from this explanation, the cluster theory attempts to explain this effect by assuming the formation of abnormally large clusters with such vapors of high dielectric constants and strong electronegative properties. The cluster theory would expect the presence of only enough of the negative molecules to form the large clusters. The small ion theory would demand concentrations of the vapor sufficient to produce the requisite number of Barus nucleii. No decisive differentiation between the theories can be made in this field until quantitative determinations have been made on the lowering produced by different percentages of the negative vapors. The net result of this discussion of the effect of mixtures has been to show that the small ion theory is capable of explaining these effects about as well as the cluster theory can. Under these circumstances these phenomena may not be urged as arguments against a small ion theory.

4. *Condensation Experiments.*

The phenomenon of the condensation of supersaturated vapors on ions or nucleii is very closely allied to the action of certain vapors on the mobilities. C. T. R. Wilson [16] found that ions present in dust-free gases saturated with water vapor, alcohol vapor, etc., would, if the gas were adiabatically expanded, cause the vapor to condense on them and to form a cloud of drops even when the expansion was well below the amount sufficient to cause such condensation in ion-free air. In the case of water, the negative ions became condensation centres on an expansion to 1.25 the former volume, the positive ions on an expansion to 1.34 the former volume. With other gases, the positive ions act more readily than the negative ions. The values given above for water correspond to a four-fold supersaturation in the case of the negative ions. In dust-free air on eight-fold supersaturation, the condensation takes place in the absence of ions.

J. J. Thomson [18] worked out the energy relations involved in the formation of drops for different conditions of supersaturations as determined by the forces of condensation, evaporation, surface tension, and electric attractions. A drop once formed under given conditions of supersaturation will not necessarily grow to a larger drop. This is due to the action of surface tension in increasing the vapor tension. An electric charge placed on a drop that might even be evaporating under the conditions in which it is placed when uncharged would preserve the drop and aid it in passing the critical stage in its growth to a visible cloud particle. The manner in which the drop acquires its charge has no influence on this action; so that it makes no difference whether the drop grew from a cluster ion or became charged through picking up an ion after being formed. The small ion theory is then in perfect accord with the condensing action of ions.

The cluster theory, on the other hand, demands that some of the drops be formed by the ions which pass through the intermediate stages between ion and drop, such as those that the Langevin ions were supposed to represent. Accordingly, the existence of the Langevin ions was initially used as a first-class argument for the cluster theory. On this theory the normal cluster ion in supersaturated gases was supposed to grow through the two classes of the so-called Langevin, or slow, ions and to finally become a regular drop. This has since been shown to be wrong by Pollock.[17] Pollock comes to the conclusion that the Langevin ions consist in all cases of solid particles of minute dimensions surrounded by a mantle of water vapor or liquid water and carrying an electric charge. This is strikingly borne out by the fact that these ions never develop in dust-free air. The charge on these ions assumes only a secondary rôle, leading to the electrical detection of the particles, and was probably acquired in a manner similar to that by which the oil drops of Millikan acquire their charge. Other than the Langevin ions, no intermediate ions have ever been detected. It is therefore evident that, unless the existence of the intermediate ions is so transient that they cannot be detected, the cluster theory leads to conclusions that are not in agreement with the facts.

The difference in condensing power of the positive and the negative ions in different gases needs some explanation. The substances exhibiting these properties are distinctly electrically polar in nature. If a droplet of one of these substances should pick up an electric charge, one would expect the charge to go to the centre of the droplet. The polar elements in the drop would arrange themselves so that the charged parts of the molecules directed outwards would be of the same sign as the charge picked up. It is to be expected that in a vapor having strong electronegative tendencies (*i.e.,* strong tendencies to acquire negative electrical charges) the molecules would more readily attach to a surface of predominating negative sign than one of the opposite sign. Accordingly, in the case of water vapor, it is not surprising that the droplets should grow more rapidly if they have negative charges than if they have positive charges. The cloud formation then takes place more easily on the negative than on the positive ions. For alcohol vapor, which appears to be less negative, the reverse seems to be true. This suggestion of the mechanism of condensation is independent of the theory assumed. It enables one to avoid explaining the action as due to a difference of dielectric constant of the vapor molecules for charges of opposite sign by substituting for this the assumption that the action depends on the electrical nature of the forces of association (*i.e.,* chemical forces) where preferences for charges of different sign are known to exist.

5. *Temperature Coefficient of Mobility.*

The temperature coefficient of mobility has been very incompletely studied. Phillips [19] and also Kovarick [20] determined the mobilities of the ions in air at temperatures ranging from 84.5° to 698° absolute with varying densities, correcting their results to reduce them to constant densities. Above 300° Abs. there was no change appreciable with temperature. Below that temperature the mobilities seemed to decrease somewhat with the temperature, this decrease being much greater in the results of Kovarick than of Phillips. Erikson [21] reported measurements on mobilities, using a method which allowed the density to be kept constant. The latter measurements are but few in number and cover temperatures between 80° and 300° absolute. The mobilities were found to be perfectly constant down to the lowest temperature, where a lowering of 10 per cent. was found. Both Phillips and Erikson reported that the difference in the mobilities of the positive and the negative ions seemed to disappear at the lower temperatures. Kovarick worked only on negative ions.

The cluster theory explains the independence of mobility and temperature as due to the fact that as the temperature goes down the size of the cluster increases; this increase, however, is balanced by the decrease of the viscosity of the gas with the decrease in temperature. If the results of Kovarick be accepted as correct, the increase in the size of the cluster proceeds more rapidly than the decrease of viscosity of the gas. The effect is contradicted to a large extent by the results of both Erikson and Phillips, so that it seems questionable. Sutherland,[7] using methods similar to those he used in calculating the change of gaseous viscosity with temperature, developed a mathematical theory of the variation of mobilities with temperature based on the small ion concept. This theory reproduced the variations of mobility with temperature observed by Phillips with remarkable accuracy. The Sutherland [7] theory of the small ion here seems to have a distinct advantage over the cluster theory, inasmuch as it can actually predict the behavior of the ions with temperature quantitatively.

The disappearance of the difference of the positive and negative mobilities at the lower temperatures may be accounted for by ascribing the difference of the positive and negative mobilities to the cause already assumed. At low temperatures the increased densities of the gases and the slower heat motions of the molecules greatly increase the probabilities of union between the electrons and molecules to form negative ions. In this way the mobilities measured for the negative ions will approach those of the positive ions. This explanation is independent of either theory.

6. *Mobilities at High Temperatures.*

The mobilities of the ions at the higher temperatures, ranging from 450° to 1900° C., have chiefly been measured in flames. Since, in this case, chemical reactions play such tremendous rôles and the numbers of the charged particles are very great, the results become very complicated. The complexity of conditions further has resulted in seriously conflicting results being obtained by the different observers. It therefore seems inadvisable to attempt to judge the theories on the basis of any of these results.

7. *Pressure Coefficient of Mobility.*

The mobility has been found to vary inversely with the pressure in air over a very large range of pressure extending from 100 atmospheres down to 1/10 atmosphere for the negative ions, and down to 1/1000 atmosphere for the positive ions.[22, 23, 20, 6, 1] At the higher end of the pressure range the mobilities are found to decrease slightly less rapidly than the inverse pressure law would lead one to expect. At 1/10 atmosphere in the case of the negative ions all observers agree in concluding that the mobility of the negative ion in air (other gases at other pressures) appears to increase abnormally rapidly.[24, 20, 25] The positive ions have been observed to do this only according to the results of one observer,[26] which have been called into question by the more recent and careful experiments of Wellisch.[1] The results of Wellisch showed not only that the positive ions have normal mobilities down to the lowest pressures ever worked with, but that the abnormal increase in the mobilities with decreasing pressure for the negative ions was only *apparent*. His results showed that in his mobility measurements there were large numbers of unattached electrons present, at all pressures below ten centimetres of mercury, that reached the plate of his measuring apparatus. In the measurements which he made, however, these electrons did not completely mask the point where the normal ions began to appear. Besides the electrons, whose number apparently increased as the pressures were reduced, Wellisch found that there were negative ions with mobilities regularly inversely proportional to the pressure down to the lowest pressures at which he could make measurements. In the analysis of the methods of making mobility determinations it was shown that a small number of electrons that did not unite to form ions before reaching the gauze could raise the apparent values of the negative mobilities. As pressures are decreased, the chance of an electron uniting with a molecule is decreased; for the free paths of the electrons and molecules vary inversely with the pressure, while the dimensions of the apparatus are sensibly unchanged. The number of electrons passing through the gauze is therefore rapidly increased as the pressure decreases. In some of the experiments of Wellisch at the lower pressures nearly as many as 50 per cent. of the carriers between the plate and gauze were electrons. In measurements where the electrons are not detected as carriers the effect of their presence must have altered the shapes of the curves in such a way as to give absolutely fictitious and high values for the mobilities. Such was the case with all of the earlier observers at low pressures with the negative ions. The mobilities of the ions are all, therefore, strictly inversely proportional to pressures up to 100 atmospheres.

Before the cause of the abnormally low mobilities of the negative ions was shown by the work of Wellisch, the assumption of the labile cluster ion which began to shed some of its molecules at pressures of about 10 cm. of Hg in air was essential. This excuse for assuming a cluster ion is now obsolete. The assumption of a cluster theory is, however, still in perfect harmony with the behavior of the ions as regards the inverse pressure law. The small ion theory is also in perfect accord with these results, since the abnormal negative mobilities at low pressures have been explained. The abnormal decrease of the mobilities at the high end of the pressure range is not explained on either theory, though it is doubtless a real phenomenon, having been observed by all observers, Dempster,[27] Kovarick,[29] and McLennan,[28] at these pressures.

8. *Mobilities and the Value of the Ratio X/p.*

A crucial test which should enable one to judge between the two theories lies in the behavior of the ions when subjected to very high velocities. The energy acquired by an ion due to an electric field depends on the magnitude of the field acting on the ion and the time over which it acts. It therefore follows that the energy will be the greater, the greater the product of field strength and mean free path of the ion becomes. It will be more convenient to substitute for this product the value of a ratio X/p, (which is proportional to it) where X is the field strength in volts per centimetre and p is the pressure in millimetres of mercury. On a cluster theory it would be expected that an ion would shed some of its attendant cluster of molecules before it acquires sufficient energy to ionize other molecules by impact; *i.e.*, before the conditions for initiation of ionization by collision set in. Such a shedding would result in an abnormally rapid increase of the mobility with an increase in the value of the ratio X/p. The small ion theory would not predict such a result, the mobility remaining essentially normal.

The apparent abnormally rapid increase of the mobilities of the negative ions as the pressure was reduced was formerly ascribed to the above type of shattering of the cluster. Townsend[25] fixes the value of X/p for the shattering of the negative cluster at about 0.2 or less. However, in light of the experiments of Wellisch, this explanation of the negative mobilities at low pressures is now no longer valid.

Up to 1915 no determinations of mobilities at high values of X/p had been made at higher pressures except those resulting from the study of the discharge of points. Chattock[30] and Tyndall[31] found normal mobilities of the ions in fields up to strength of 3000 volts per centimetre; *i.e.*, values of $X/p = 4$. Later measurements by Tyndall[32] indicated a possibility of abnormal increases of mobilities with increasing ionic currents. In a letter to the writer, Professor Tyndall states that he now " has reason to doubt the accuracy of those results " so far as this effect was concerned. Franck[33] and also Moore,[34] in fields of about 10,000 volts per centimetre, apparently obtained abnormal mobilities for both ions. They were working near the threshold of glow discharge where the uniformity of their fields as well as the value of their field strengths are to be questioned. In 1916 the writer,[2] using a modification of the Rutherford alternating-current method for determining mobilities and using high-frequency oscillations of the Chaffee arc, determined the mobilities of the ions in dry air at fields as high as 12,000 volts per centimetre; *i.e.,* $X/p = 18$. He found only normal values of the mobilities, the negative ions in no case showing a tendency to increase relatively to those of the positive ions. Ratner,[35] in a still later paper, finds perfectly normal mobilities of the positive ions up to the point of the glow discharge, using a modification of the Chattock and Tyndall[30,31] method. The negative ion in his results appears to acquire abnormally high mobilities in fields of 1800 (volt per cm.) in air at atmospheric pressure; *i.e.,* $X/p = 2.4$. He also detects large numbers of electrons acting as carriers by this method. The method used consists in accelerating ions generated by a radioactive substance or an incandescent wire by means of an electric field, and measuring the wind-pressure produced. This pressure is measured by the deflection of a light vane which can give only the relative values of the pressures, but not absolute values. In order to calibrate the vane to give the absolute values of the pressures, mobility measurements were made on ions in normal fields, where they are known, and the pressures computed from these results. In the case of the negative ions, Ratner's method encounters difficulties through the fact that the measurements are made on very freshly generated carriers, among which, according to him, are appreciable numbers of unattached electrons. The method which he uses assumes that if the ions move with *uniform* velocities the pressure due to the drag of the ions on the gas molecules is equal to drX, where d is the distance between the plates, r is the density of electrification of one sign, and X is the field strength. Since the electrons combine to form the ions all along their paths through the field, the condition of uniform velocity is not fulfilled. As a result of such an action, it is not surprising that Ratner obtained abnormally high mobilities for the negative ions. Chattock and Tyndall got no such effect at nearly twice the values of X/p which he used on the negative ions, though they used essentially the same method. In their case the carriers were generated by the point discharge. It is quite possible that such carriers are, at the lower field strengths in point discharge, generated as ions directly, and that consequently there were but few electrons present in the determinations.

The conclusion to be drawn is that the ions show *no* tendency to take on abnormal values of the mobilities for any values of the ratio of X/p up to the point where ionization by impact begins.

These results speak unmistakably against the labile cluster theory. Furthermore, if an apparent breaking up of a negative cluster did appear, as is assumed by Ratner, the cluster theory would encounter considerable difficulty in explaining why it is that the positive cluster is so many times more stable than the negative cluster.

9. *Free Electrons.*

It was early noticed by Franck and Pohl [3, 4] that the negative carriers in very pure samples of He, Ar, and N_2 had remarkably high mobilities. These were correctly explained on the assumption that negative carriers in the gases were in part free electrons. Recently Haines [5] and also Wellisch [1] have shown that a small fraction of the carriers in hydrogen and air are also of this nature. In air the number is too small to detect at ordinary pressures, but they become appreciable at about 10 cm., according to Wellisch. The presence of electrons as negative carriers, as well as normal negative ions in most of the common gases, may be explained in two ways. Wellisch [1, 46] assumes that the electrons exist *permanently* in those gases as carriers. The percentage of carriers of this type that exist in a gas depends on the pressure and the nature of the gas. To explain this fact, Wellisch assumes that in order for an electron to form an ion by union with a neutral molecule the electron requires a certain threshold value of kinetic energy. This the electron acquires at the instant of ionization from the ionizing source; *e.g.*, X-rays, or alpha particles. The expulsion of the electron leaves the parent molecules with a residual positive charge. As the electron recedes from the molecule, some of its kinetic energy is converted into potential energy of separation. This conversion of the energy might become sufficient to lower the kinetic energy of the electron below the threshold value for ion formation. This would be more likely to occur, the smaller the initial energy of liberation of the electron the longer the mean free path, and the higher the value of the kinetic energy required. The latter would depend on the electrochemical nature of the gas. Therefore, the electrons which recede too far from the parent molecules before encountering neutral molecules will be unable to form ions and will be the free electrons of Wellisch. This theory, though very pretty, is open to one objection. The experimental curves obtained by both Wellisch and Ratner indicate that union between electrons and molecules takes place all along the space between the plates; *i.e.,* apparently intermediate ions of all mobilities between electrons and ions are present. On the above view of Wellisch the curves should appear as if they were composed entirely of two groups of carriers present in very definite ratios from the start, which is obviously not the case. The theory of Wellisch is further open to test, for with different ionizing agents the electrons should receive different amounts of energy at the start. As a result the pressures at which the free electrons just begin to appear in a given gas should depend to some extent on the ionizing source.

J. J. Thomson[36] recently attempted to explain the existence of the electronic carriers as follows: He assumed that an electron and a molecule did not necessarily form an ion on every encounter, an assumption which seems plausible, as it might be expected that it would be necessary for an electron to strike certain definite localities in a molecule before it could be incorporated in the form of an ion. He further assumed that the chance that a single collision between the two would result in ion formation was $1/n$, where n is a number (possibly very large) characteristic of the gas only. On the basis of these assumptions he mathematically deduces the consequences which would be expected if the mobility of the ions could be measured ideally by a simplified method. In practice, if n were great or the mean free path were long (*i.e.,* pressure low), it would be expected that the electrons might traverse several centimetres in the gas without union to form ions. This is the more likely as the mean free path of the electron is supposed to be quite long. The mobilities of negative ions determined in a gas of electropositive properties (*e.g.,* where n is large and at low pressures) would then apparently be abnormally high, as previously explained, while considerable numbers of free electrons would be detected between the plates.

Haines reported in the papers in which he shows the existence of the electronic carriers in hydrogen that, besides these and the normal negative ions, he finds evidences of groups of ions of intermediate mobilities. These he at once ascribes to clusters of different compositions. The curves which give this evidence show marked bends at potentials lower than those required to detect the normal negative ions, an effect that is totally absent in the curves of Wellisch and of Ratner. The positive ions appear to behave perfectly normally. The writer feels inclined to seek for the cause of these results in peculiarities of the method of determination, in view of the contradictions above mentioned.* In his determinations Haines used a distance between the plate and the gauze in the Rutherford alternating-current method varying from four to ten centimetres. The plates and gauze are closely surrounded by the glass insulating walls of the measuring chamber used. These glass walls, from the writer's own experience, may become highly statically charged through the diffusion of the ions to them. In the case of the negative ions, where numbers of rapidly moving free electrons are able to migrate to these walls, this effect could become appreciable. Further, in Haines's earlier experiments a stream of gas was constantly passing through his gauze. These three factors would all tend to distort the field between the plate and the gauze, making it far from uniform, and it is possible that this lack of uniformity of the field caused the distortion of the curves reported. In this connection it might be pointed out that Todd[26] in his mobility measurements used plate distances of ten centimetres. He was later forced to repeat his experiments, using a series of annular disks connected to a potentiometer in his field in order to keep his field uniform. This proceeding considerably modified his later results.

From the foregoing it seems that the explanation offered by J. J. Thomson of the existence of the electron as a carrier in the mobility determinations is the best adapted for use, particularly as it leads to considerations that are included in the discussion of the methods of mobility measurement. With this view of the existence of the free electrons, it seems wrong to assume that a comparatively stable cluster of neutral molecules surrounding a negative electron could exist in the gases where the electron shows so much reluctance at uniting with a single molecule. The comparatively weak forces appearing to exist between free electrons and molecules speak more in favor of a small ion theory. It must consequently be concluded that in this case the small ion theory again has a distinct advantage over the cluster theory.

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* Recently Mr. K. L. Yen, at the University of Chicago, has made some determinations of the mobility of the negative ions in a number of gases, in which, though both normal negative ions and free electrons were found, no traces of intermediate negative ions could be noticed. The results will, I believe, be published shortly.

10. *Conclusion.*

In reviewing the preceding considerations one is forced to conclude that the concept of a *labile* cluster ion is not well adapted to explain the properties of the gas ions, since it encounters serious difficulties in explaining (1) the independence of the mobilities and the value of the ratio X/p, (2) the reluctance of electrons to unite to form ions with ordinary molecules, and (3) the absence of intermediate types of ions to be expected from the growth of an ion to a drop in the condensation experiments. In most other respects the explanations furnished by the labile cluster theory seem entirely adequate to account for the phenomena, so far as one is able to judge from the meagre experimental data available. With the exclusion of the *labile* cluster theory it is still possible to explain the initial five-fold lowering of the mobility coefficients by assuming the formation of a very *stable* cluster ion. This must be an extremely stable cluster that is capable of withstanding the action of fields with high values of X/p, and which must depend for its other properties on actions similar to those assumed for the small ions. Unfortunately the second objection urged against the *labile* cluster theory becomes a still more serious objection to this theory.

One is accordingly forced to turn to the small ion theory in some form or other, as this *apparently has no serious contradictions* in the light of foregoing analysis. Some nine or ten mathematical theories, giving as many different equations showing the relationship between the mobilities of the ions and the various molecular constants, have been proposed by Riecke,[37] Langevin,[23, 43] Lenard,[38] Thomson,[39] Reinganum,[40] Sutherland,[7] Wellisch,[6] Przibram,[41] and Kleemann.[42] These theories have been deduced starting from various assumptions based on kinetic theory of gases. All of these theories, with the exception of that of Wellisch, provided one excludes those containing indeterminate constants, lead to equations which, when evaluated in terms of the molecular constants, yield values of the mobilities from five to ten times too high. These defects of the theory are at once ascribed to the existence of a cluster whose existence had been ignored in setting up the equations by the men who incline to the cluster theory. In the case of the advocates of a small ion theory the discrepancy between the mobilities expected from the theory and the actual observed mobilities is ascribed to an increased drag produced on the ions by the action of their charge on the neutral molecules, a factor which had been omitted in the initial deduction. In either case, in order to make the theories yield correct results, an arbitrary numerical factor is introduced into the equation, so that the mobilities obtained from it are of the correct order of magnitude.

The small ion theory of Wellisch [6] is the only one which starts from accepted theoretical considerations, and without resort to any arbitrary numerical factors yields correct values for the mobilities. The theory, unfortunately, has one serious defect. A term $R=(K-1)e^2/8\pi\ ns^4$ is introduced into the equation, as well as into most of the cluster theory equations above mentioned, which is supposed to be related to the apparent increase in size of the ion due to its charge. R is the potential of the ion of charge e on a neutral molecule of dielectric constant K (if such a term may be used) at a distance s. K is taken as the value of the dielectric constant of the gas in bulk. The use of this factor R in a small ion theory is *not correct.* To the writer's mind it seems equally questionable whether it is legitimate to use it in any ion theory, for the reasons which follow:

1. An atom is now pictured as a rather diffuse system of electrons surrounding a highly charged minute positive nucleus. If a single unit charge concentrated in an electron be placed within a distance comparable to the diameter of such a neutral atom or molecule, it seems absurd to assume the potential energy of this system would be the same as that for a mass of many molecules in bulk. It is consequently very questionable whether it is proper under any such circumstances to use this equation at all.

2. This law, furthermore, leads to the formation of a very stable cluster ion in air if the proper values are introduced for the various quantities. This may be seen from the computations below, where it becomes evident that a temperature of 1190° absolute, or a field of over 16,080 volts per centimetre at 760 centimetres Hg pressure, is required to cause this ion to begin to disintegrate, assuming a mean free path of the ions equal to that for normal gas molecules. This ion cluster, at least to within a molecular diameter beyond that of the central molecule, would therefore have a stability exceeding that of some chemical compounds. A term such as R introduced into the *small ion theory* of

Wellisch would make it *meaningless,* for the term leads inevitably to a cluster formation.

For a cluster in which the factor R appears:

$\frac{R}{K.E.}$ at 0° and 760 mm. Hg pressure of air, is,

$$\frac{R}{K.E.} = \frac{(K-1)e}{4\pi n m v^2 s^4} = \frac{(K-1)e^2}{12\,\pi P s^4} = \frac{(.00058)(4.8 \times 10^{-10})^2}{12 \times 3.1 \times 1.01 \times 10^6\,(3 \times 10^{-8})^4} = 4.37$$

$K.\ E.$ is kinetic energy of surrounding gas molecules.
P = atmospheric pressure in dynes.

i.e., potential energy of cluster is greater than the kinetic energy of the surrounding gas molecules. The ion is therefore stable.

The temperature for which $\frac{R.}{K.E.}$ equals unity, *i.e.*, the break-up temperature of the ions, is 4.37 × 273° = 1190° Absolute.

The value of the electric field (X) necessary to shatter the ions if the mean free path is 9.95×10^{-6} centimetres is

$$\frac{R}{K.E.} = 1 = \frac{R}{\frac{1}{2} m v^2} = \frac{R}{Xe\lambda} = \frac{(K-1)e^2}{8\pi X n \lambda e s^4} \quad \text{where } \lambda = \text{mean free path of molecules of air.}$$

$$X = \frac{e(K-1)}{8\pi n s^4 \lambda} = \frac{5.8 \times 10^{-4} \times 4.8 \times 10^{-10}}{8 \times 3.1 \times 2.6 \times 10^{19} \times 9.9 \times 10^{-6} (3 \times 10^{-8})^4}$$

$$= 16{,}080 \text{ volts per cm.}$$

or a value of $X/p = 21.2$, *i.e.*, assuming λ for gas ions to be the same as that of molecules.

The one small ion theory that is free from such an assumption is that of Sutherland. This theory, however, is one of those which is forced to include an arbitrary constant in order to make it yield the true mobilities of the ions. It is the theory which successfully yields the variation of mobility with temperature found by Phillips. The theory also predicts the Kaufmann law between mobilities and the molecular weights of the gas in which the ion moves. As this theory is a small ion theory, as no serious objections may be raised against it, as it appears to predict some of the more fundamental laws of ionic behavior quite well, and, finally, as it is well adapted to expansion as the knowledge of the structure of molecules advances, it seems to the writer to be the most successful ion theory yet proposed.

In conclusion the writer desires to express his sincere thanks to Prof. R. A. Millikan for his valuable criticism of this paper and his kind interest in it. The writer's thanks are also due to Dr. N. E. Dorsey for his kind advice. The writer desires to acknowledge his indebtedness to the excellent review of the field of mobility measurements and bibliography on mobilities of the ions prior to 1912 included in a paper by Franck,[14] entitled "Bericht über Ionenbeweglichkeit."

NATIONAL BUREAU OF STANDARDS,
Washington, D. C.,
June 12, 1917.

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Electrolytic Pickling Process and Its Effect on the Physical Properties of Iron and Steel. J. COULSON. (*Proceedings of the American Electrochemical Society,* October 3–6, 1917.)—Brittleness of steel springs resulting from acid pickling and electroplating is a well-known phenomenon. Tempered springs which are pickled even for a few seconds in an acid bath snap when subjected to strain. Such springs, however, can be electrolytically pickled without destroying their resiliency. It is known that metals absorb gases and that the amount absorbed depends upon the nature of the gas, the condition and character of the metal, and the surrounding medium. These absorbed gases appear to have an important influence on the behavior of iron, steel, and certain alloys. Electrolytic iron is extremely brittle, due principally to occluded hydrogen, and there appears no doubt that the brittleness of steel springs after pickling is caused by the absorption of hydrogen during the ordinary pickling process. The effect is still more pronounced if the springs are made the cathode in an acidulated electrolyte.

To determine the embrittling effect of adsorbed hydrogen upon steel pickled in different ways, samples of steel wire were pickled chemically by simple dipping in acid, also by electrolytic pickling, using them as cathodes or as anodes. Oscillation tests on the original wires, sand blasted, and three sets treated as described, showed the chemically cleaned and the cathodically cleaned to be very brittle, while the anodically cleaned had the strength of the original samples. Similar tests were aso made with drill-rod steel, hot-rolled Bessemer, and cold rolled steel, after which mechanical tests were made as to strength, elongation, and reduction of area. The chemically and cathodically cleaned specimens again showed greater brittleness, which was most marked with the high-carbon steels and less marked with the soft steel.

PHYSICS OF THE AIR.*

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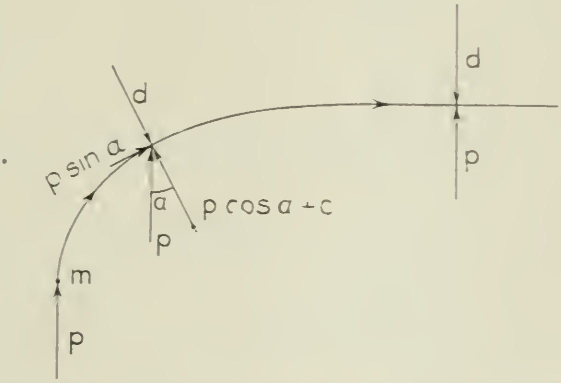
CHAPTER VIII (*Continued*).

Automatic Adjustment of Winds in Direction and Velocity.—In discussing the more extensive winds it is convenient to consider the earth as stationary and the air as moving over it without friction under the influence of three distinct horizontal forces: (1) The deflective force, due to the earth's rotation; (2) the horizontal component of the centrifugal force, due to the curvature of the path, and (3) the horizontal or gradient pressure, due to gravity. The first two are at right angles to the course of the wind and therefore help to control its direction, but do not alter its speed. The latter, however—that is, the gradient pressure—affects both the direction and the speed. Furthermore, as the velocity depends upon the horizontal pressure alone, and as the other forces depend in turn upon the velocity, and are zero when it is zero, it follows that of the three forces only the gradient pressure is independently variable.

FIG. 39.



Deflection and path of winds in frictionless flow under a force of constant magnitude and constant geographic direction.

Consider, then, the result of applying a horizontal pressure p of constant magnitude and constant geographic direction to a small mass m of air, free, as above assumed, from friction: Let m, Fig. 39, be the mass in question initially at rest with reference to the surface of the earth, and let it be acted on by the force *p*, exactly poleward, say. Immediately the mass moves, under the applied pressure *p*, the deflective force *d* becomes operative, thus curving the path (to the right in the northern hemisphere, to the left in the southern) and introducing the centrifugal force *c*. So long, however, as the angle between the path and the force *p* is less than 90 degrees there will still be a component of the latter in the line of motion; accordingly the speed of *m* will continue to increase, and therefore also the deflective force *d*. If this angle should exceed 90 degrees, the force *p* would have a component opposite to the direction of motion, which consequently would be slowed up and *d* thereby correspondingly decreased. In the end, therefore, a poleward force along the meridians on an object free to move gives it an exactly west to east velocity of such magnitude that, except in very high latitudes, the resulting deflective force is nearly equal to the horizontal pressure—the horizontal component of the centrifugal force being then comparatively small, except near the poles. Whatever the direction of the gradient force, whether poleward, as above assumed, or any other, the final motion is normal thereto.

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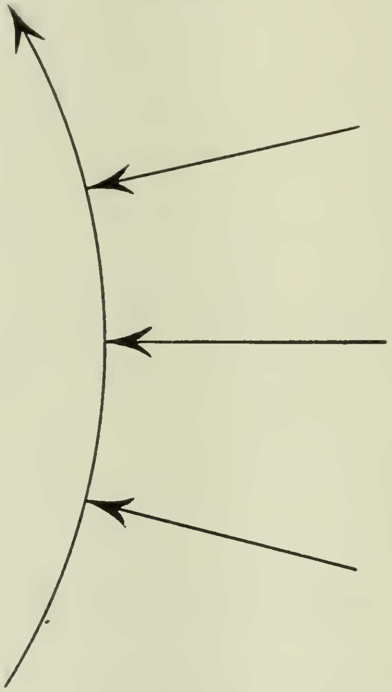
* Continued from page 674, vol. 184, November, 1917.

Fig. 40.



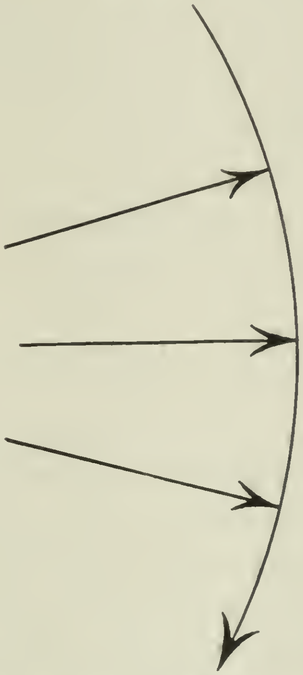
Path of winds in frictionless flow under a converging force.

A change in the magnitude but not in the direction of p, above, would only shift the latitude of the path and change the velocity so as to be nearly proportional to p.

If the horizontal pressure is not everywhere in the same direction, but converges, as in Fig. 40, or diverges, as in Fig. 41, the path, in adjusting itself normally to the directions of this pressure, obviously curves, as in cyclonic and anticyclonic regions, respectively.

In all cases, then, the wind automatically follows approximately the isobar of its position, with substantially the gradient velocity.

FIG. 41.



Path of winds in frictionless flow under a diverging force.

General Relations of Wind to Elevation.—Knowledge of the directions and velocities of the winds of the earth is still fragmentary and incomplete. Over large areas even the surface winds are unknown, and over regions best studied these alone are well known. The continuous records obtained at mountain stations have given much information in regard to air movements, but stations of this nature are comparatively few, and, besides, their data, however valuable, are always affected to an unknown extent by local topography. Cloud observations have also given a large amount of valuable information, but it, too, is only fragmentary. At best a cloud observation seldom gives more than the direction and velocity of the air at one level, nor does such an observation ever apply to the stratosphere, since this region is never visited by clouds. In many respects kites and sounding balloons have furnished the most valuable data in regard to the movements of the upper air and their causes, but, unfortunately, aerological investigations of this nature, with relatively few exceptions, have been restricted to the northern hemisphere, and even there mainly to the summer season. Nevertheless, by combining the data gathered from these various sources a number of tentative conclusions, subject, of course, to modification, have already been reached in regard to the winds of different parts of the world from the surface up to great elevations. Some of the more important of these conclusions are:

> 1. That there is no continuous and rapid overflow of the atmosphere at all longitudes from the equatorial to the polar regions. At an elevation of 10 kilometres, for instance, the wind of middle northern latitudes seems to have southerly components about as often as northerly.

From this it follows that the equator-polar circulation is irregular and probably complex even at the higher altitudes.

> 2. That the equatorial winds are not always and at all levels from the east; that, on the contrary, west winds occur (how regularly is uncertain) at elevations of about 18 to 20 kilometres, with east winds again prevailing (certainly at times) at still greater elevations.

The cause of this layer of equatorial west wind has never been explained. Indeed, it may be only a local and temporary phenomenon.

> 3. That layers of air in which the temperature increases with increase of elevation, and others in which the temperature is constant, exist at different levels, especially through the first two or three kilometres. This stratified condition of the lower atmosphere appears to be universal. It is found even over tropical oceans, and is exceedingly well developed over the ice plateau of Antarctica.

Each layer usually shows such different humidity and such different wind velocity from those of the adjacent layers as to indicate a distinct origin, which it well may have. As explained, for example, in an earlier section, a rising convection current on reaching its equilibrium level flows away substantially at that particular elevation, and obviously retains its own humidity (provided condensation has not taken place), dust content, and other peculiarities. Its viscosity is not the same as that of the adjacent air, because its humidity or temperature, or both, are different. Hence, as shown by billow clouds, any such layer with a distinctly independent velocity tends to retain its integrity and to glide over another from which it differs physically without rapid intermingling. And there are still other obvious causes of temperature and humidity irregularities and consequent stratification of the atmosphere, such as reflection from, and evaporation of, clouds, surface cooling, and air drainage. Clearly, then, one should expect to find in the lower atmosphere substantially the kind and amount of temperature inversions and other irregularities that it actually shows.

> 4. That the upper winds are exceedingly variable along the edges of the high-pressure belts, and that marked disturbances occur in the antitrades.
>
> 5. That the north-poleward pressure gradient in the upper atmosphere becomes very small long before the arctic circle is reached—in fact, between 50° and 60° N.
>
> 6. That in high northern latitudes, where the poleward pressure gradient of the upper atmosphere is small, the westerly winds are not constant.

Local Wind Velocity and Elevation.—Everyone knows that the wind increases with increase of elevation. Even casual observations of such objects as sails of ships, tops of trees, columns of smoke, or isolated clouds suffice to show qualitatively that wind velocity increases with height above the surface; while measurements made by triangulation on freely drifting clouds and balloons, or by anemometry on tethered kites, fully support the conclusions reached by the simpler methods just mentioned. Near the surface of the earth—up to from 2 to 8 metres over an open plain—the condition of the wind, upon whose force this limit depends, may be summarized as follows:

Actual velocity: exceedingly irregular.
Average velocity: increases rapidly with elevation.
Rate of velocity increase: { *a*, increases with average velocity.
{ *b*, decreases with elevation.

Above this thin surface layer the wind increases so nearly regularly with elevation that its approximate velocity at any level up to 16 metres may be computed, according to Stevenson,[38] from its observed velocity at some other height by the empirical equation,

$$V = v\sqrt{\frac{H + 72}{h + 72}},$$

in which V is the computed wind velocity for the level H in terms of the known velocity v at the height h, both elevations being expressed in feet.

If heights are given in metres, this equation becomes,

$$V = v\sqrt{\frac{H + 22}{h + 22}}.$$

Other empirical equations expressing the relation of wind velocity to elevation have been given for greater heights. Douglas,[39] for instance, finds that his velocity observations between 100 metres and 600 metres elevation fairly satisfy the simple equation,

$$\frac{V}{v} = \left(\frac{H}{h}\right)^{\frac{1}{4}}.$$

Shaw [40] suggests as a likely formula,

$$V = \frac{H + a}{a} V_o,$$

in which V is the wind velocity at the height H above *ground*, V_o the observed anemometer velocity at a fixed position, and a a constant, obviously depending upon surrounding topography, anemometer exposure, and, perhaps, other factors.

Among the most interesting observations on the relation of wind velocity to altitude are those of Dr. Cesare Fabris,[41] based on some 200 pilot balloon flights made at nearly equal intervals during the year June, 1910, to May, 1911, at Vigna di Valle, the principal aerological station of the Royal Italian Oceanographic Committee. This station is about 25 miles northwest from Rome.

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[38] *Jour. Scot. Meteor. Soc.*, 5, p. 348, 1880.

[39] *Nature*, 33, p. 593, 1885.

[40] Advisory Committee for Aeronautics, Reports and Memoranda, 66, No. 9, p. 8, 1909.

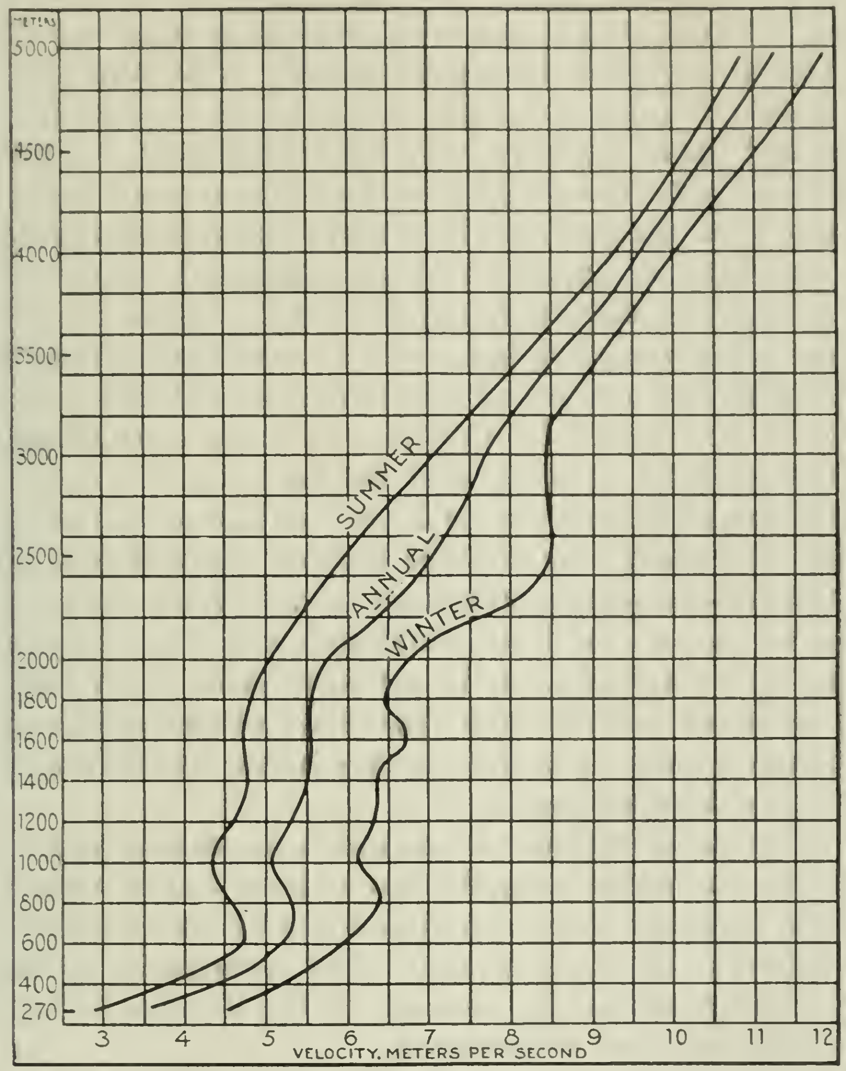
[41] *R. Comitato Talassografico Italiano*, Memoria 8, pp. 37–46. 1912.

Its coördinates are: Latitude 42° 04′ 41″ N.; longitude, 12° 12′ 43″ E.; altitude, 272.4 metres.

The general results of all the observations are summed up in Fig. 42, which shows four distinct regions:

a. The region of rapid linear increase of velocity with increase of altitude, extending from the surface (272 metres above sea level), where the velocity is least, to an elevation above ground of, roughly, 300 to 500 metres. This obviously is the region in which the winds are affected by surface friction and the resulting turbulence. Clearly, too, the average number of eddies and their consequent effect on velocity must rapidly de-

FIG. 42.



Wind velocity and elevation. (After Fabris.)

crease with increase of elevation, at least near the surface, substantially as indicated by the given velocity-altitude curves.

b. The region of velocity decrease with increase of altitude; about 200 metres thick and coming immediately above *a*. This decrease probably is not what one at first would expect, but it may be of fairly general occurrence (conclusive data are not available) in analogy to the well-known fact that the maximum velocity in rivers, canals, and other streams is not at the surface, but, roughly, one-third the depth *below* it. This surprising relation between velocity and depth is due to the retarding drag of the bed and banks, together with the viscous pull of the swifter centre that draws the sluggish surface water away from either side; and, since the surface of the earth exerts a similar drag on the atmosphere, it appears that an analogous effect on wind velocity might be suspected, not, of course, because of overflow, for there are no retarding banks, but as a result of convection.

Obviously the amount of interference to the flow of a given stratum of air, exerted by a convecting mass, depends upon the difference of their velocities and the duration of their contact. But near the surface of the earth vertical movements necessarily are slow, and again slow near the limit of convection, and therefore most rapid at some intermediate point. Hence the least interference to its flow and the maximum velocity, or at least a tendency to a maximum, of the turbulent layer of air may occur below its pseudo surface—the upper limit of convection—just as the maximum flow of a river occurs below its surface, though chiefly for a different reason.

c. A region of irregular winds slowly increasing with increase of altitude, extending, roughly, from about 500 to 1500 metres above the surface. These conditions are of very general occurrence between the levels given.[42] The irregularity probably is due to convectional mixing induced during the day by insolation and at night by cloud evaporation.

d. A region of approximately constant increase of velocity with increase of elevation, beginning at about 1500 metres above the surface and extending to at least the maximum height observed, 5000 metres. The wind velocities of this region, being out of the reach both of frictional and convectional disturbances, are determined by the prevailing horizontal pressure gradients.

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[42] Berson, *Wissenschaftliche Luftfahrten,* 3, p. 205, 1900.

Cloud and balloon observations show that increase of wind velocity with increase of altitude beyond 1500 to 2000 metres above the surface holds practically to the top of the troposphere, where the velocity in middle latitudes may amount to as much as 90 metres per second (200 miles per hour) or even more.

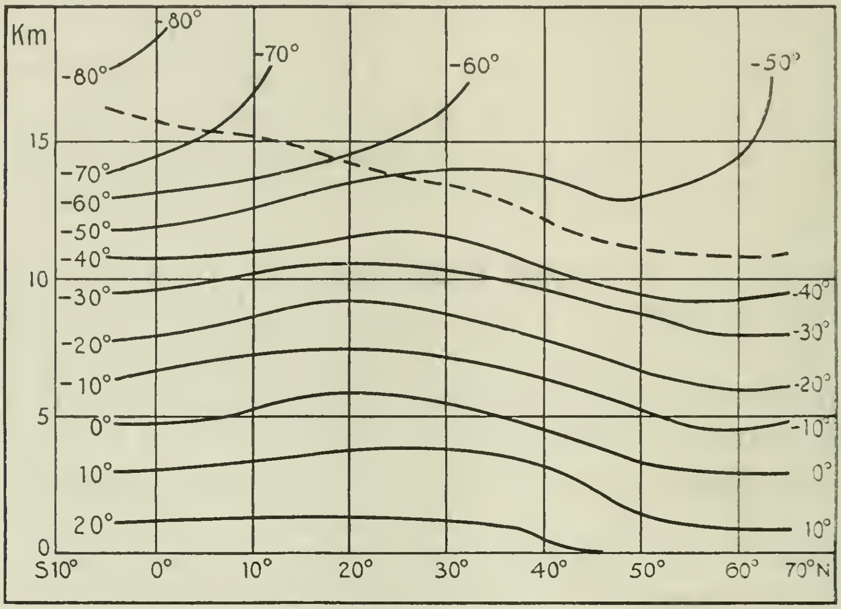
At higher levels—that is, in the stratosphere—the average velocity is decidedly less.

Horizontal Pressure Gradient and Elevation.—All these facts are well known, but there are no generally accepted and satisfactory discussions of the reasons why the average wind velocity at levels above the limit of appreciable surface influence should go on increasing with increase of elevation up to the isothermal level and then decrease. Indeed, data sufficient for a complete solution of this problem are not yet available, and it is only recently that enough facts have become known to indicate at all clearly the several links in the chain of cause and effect that determine the average atmospheric movements in middle and higher latitudes.

Because of the actual distribution of insolation over the earth the temperature of the lower atmosphere, as shown by observation, is warmest, on the average, in equatorial regions and coldest beyond the polar circles, with intermediate values over middle latitudes. Hence, since the temperature of the air above the earth depends mainly upon convection and radiation from below, it follows that the latitude distribution of temperature in the upper air must be substantially the same as that at the surface; that is, warmest within the tropics and coldest in the polar regions, with intermediate values between. And this, indeed, according to kite and balloon records, does apply at each level up to 10 to 12 kilometres, or to fully three-fourths of the air mass. At much higher levels, 15 to 20 kilometres, for reasons that need not be discussed here, the rare atmosphere is coldest over equatorial regions and warmest over high latitudes. This inverse condition, however, does not apply to the winter and summer atmospheres of the same place, nor, presumably, to those of neighboring places on approximately the same latitude. On the contrary, the atmosphere is warmer, on the average, at all explored levels during summer than during winter, and warmer, so far as known, over regions whose temperatures are relatively high than over others of the same latitude that are comparatively cold.

As a crude first approximation to conditions as they actually exist, assume (1) that the temperature distribution is the same along all meridians, (2) that the temperature changes from one latitude to another is the same for all levels, and (3) that sea-level pressure is the same at all latitudes. Assumption (1) approximates the conditions over much the greater portion of the southern hemisphere, but, on account of the irregular distribution of land and sea, has to be modified for any detailed study of the winds of the northern hemisphere. Assumption (2) conforms roughly to average conditions between the thermal equator and latitude 50° to 60°, except near the surface and at altitudes above 10 to 12 kilometres. This is well shown by Fig. 43 referring to the northern hemisphere during its summer, and copied from Süring's paper,[43] on the present state of knowledge concerning the general circulation of the atmosphere. Assumption (3), as applied to normal pressure, is also approximately true except for restricted areas, whose secondary and local effects will not here be discussed.

FIG. 43.



Relation of temperature to altitude and latitude. (After Süring.)

Consider an atmosphere of the same composition throughout and having initially the same temperature at any given elevation resting on a horizontal plane. Let the temperature be uniformly increased from north to south, say, and by the same amount from top to bottom, thus simulating the temperature distribution that actually obtains in the earth's atmosphere over middle latitudes, as above explained. Find the resulting horizontal pressure gradient at the different levels.

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[43] *Zeitschrift der Gesell. für Erdkunde,* p. 600, 1913.

At the height h the horizontal pressure gradient, $\frac{dp}{dn}$, obviously directed from the warmer toward the colder region, is very approximately given by the equation,

$$-\frac{dp}{dn}=p\frac{\Delta h}{HL},$$

in which L is any given horizontal distance along which dn is taken, p the pressure at the level h, above the colder end of L, Δh the difference of vertical expansion of the air below the level in question at the ends of L, or difference of distance through which the level, whose original pressure was p, was lifted at these two places, and H the virtual height of the atmosphere, approximately 8 kilometres, or height it would have above any point if from there up it had the density which exists at that point. The negative sign is used because the pressure decreases as n, measured from a warmer toward a colder region, increases. For simplicity let L be in the direction of maximum rate of horizontal temperature change, north-south, in this case.

Under the assumed conditions

$$\Delta h=\tfrac{a}{3}\Delta Th, \text{ approximately},$$

in which a is the average coefficient of volume expansion of the atmosphere below the level h, and ΔT the difference of temperature change at the ends of L.

At any two levels, then, h and h', the horizontal pressure gradients in the same direction are given approximately by the respective equations,

$$-\frac{dp}{dn}=\frac{p\frac{a}{3}\Delta Th}{HL},$$

and

$$-\frac{dp'}{dn}=\frac{p'\frac{a'}{3}\Delta T'h'}{H'L}.$$

But L may be taken the same in both equations, while a, H, and ΔT generally are not greatly different respectively from a', H' and $\Delta T'$. In reality,

$$\frac{H}{H'}=\frac{T}{T'},$$

and a' is slightly greater than a when T' is less than T. But in this case it appears from observations that actually $\Delta T'$ is slightly less than ΔT, so that

$$\frac{\frac{dp}{dn}}{\frac{dp'}{dn}} = \frac{ph}{p'h'}, \text{ approximately.}$$

Again, from the 5- to the 10-kilometre level, and even to some distance below the former and above the latter,

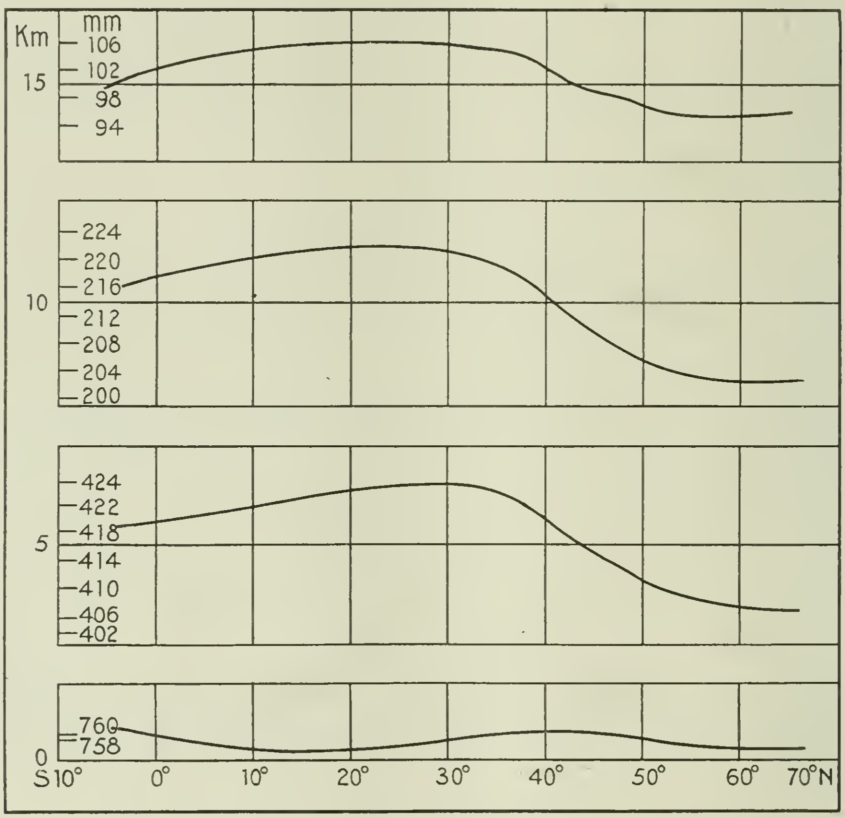
$$\frac{p}{p'} = \frac{h'}{h}, \text{ roughly.}$$

Hence, commonly,

$$\frac{\frac{dp}{dn}}{\frac{dp'}{dn}} = \frac{h'h}{hh'} = 1, \text{ approximately.}$$

That is, through these levels, or from below 5 kilometres to above 10 kilometres, the horizontal pressure gradient established by the temperature difference between adjacent regions of air

FIG. 44.



Relation of pressure to altitude and latitude. (After Süring.)

is roughly constant. This conclusion is fully supported by observations, as shown by Fig. 44, referring to the northern hemisphere during its summer, and also copied from Süring's paper.[44]

Level of Maximum Horizontal Pressure-Gradient.—The approximate level of the maximum horizontal gradient may be found as follows:

As just explained, in the equation,

$$-\frac{dp}{dn}=\frac{p\frac{a}{3}\triangle Th}{HL},$$

the factor, $\frac{\frac{a}{3}\triangle T}{HL}$, is roughly constant. Writing G for the gradient and K for the "constant," the equation takes the form,

$$G=Kph.$$

Hence G has a maximum value when

$$p\,dh=-h\,dp.$$

But

$$-dp=p\frac{dh}{H}.$$

Hence the pressure gradient is steepest when

$$p\,dh=\frac{h}{H}p\,dh,$$

that is, when $h=H=8$ kilometres, roughly.

The following is a slightly different method of arriving at the same conclusion:

The maximum horizontal pressure gradient resulting from a constant temperature difference between two neighboring columns of air obviously is at that level at which the vertical pressure is most changed by the expansion of the air below due to a constant temperature increase.

Let h be any height, and let a be the average coefficient of volume expansion of the air below this level. Then,

$$\triangle h=\frac{a}{3}h\text{, nearly,}$$

and

$$\triangle p=\rho g\triangle h=\rho g\frac{a}{3}h\text{, nearly,}$$

in which ρ is the density of the air at the level h and g the local gravity acceleration.

But $\rho=Cp$, in which C is a constant, and

$$\triangle p=p\,C.g\frac{a}{3}h=K\,p\,h,$$

say, in which K may be regarded as a constant.

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[44] *Loc. cit.*

Hence, as before, Δp has its maximum value when

$$p\,dh = -h\,dp = \frac{h}{H}\,p\,dh\cdot$$

That is, the horizontal gradient is steepest when $h = H$. But, as is well known, $H = 8$ kilometres, approximately. Hence the horizontal pressure gradient, resulting from a temperature distribution substantially that which actually obtains in the atmosphere, is greatest at a height of about 8 kilometres.

Constancy of Mass Flow—Egnell's Law.—At a distance above the surface of the earth sufficiently great to avoid appreciable retardation due to friction and turbulence—that is, at elevations greater than 2 kilometres (usually less)—the wind obviously must blow in such direction and with such velocity that there is an approximate equation between the pressure gradient on the one hand and the combined centrifugal force and deflection force due to rotation on the other. Hence, at these levels, if $\frac{dp}{dn}$ is the maximum horizontal pressure gradient,

$$\frac{dp}{dn} = -\rho v \left(2\,\omega \sin\phi + \frac{v}{R}\tan\phi\right), \text{ approximately.}$$

in which ρ is the density of the air at the level under consideration, v the wind velocity, ω the angular velocity of rotation of the earth, ϕ the latitude, and R the radius of the earth.

A little calculation shows that in the case of a wind following, roughly, a parallel of latitude the second term in the parentheses is always small, except in very high latitudes, in comparison with the first. Thus for a 22.4-metres-per-second (50 miles per hour) west wind at latitude 45° the first is about 30 times greater than the second. Hence, under these conditions,

$$\frac{dp}{dn} = -\rho\, v\cdot 2\,\omega \sin\phi\text{, approximately.}$$

But, as just explained, the horizontal pressure gradient, $\frac{dp}{dn}$, is roughly constant between 5 and 10 kilometres elevation and directed polewards. Hence, at any given latitude, $\rho\, v$, the mass flow, or mass of air crossing unit normal area per unit time, tends to remain constant with change of altitude from 4 or 5 kilometres above sea level up to the isothermal region. In other words, through this region, $\rho\, v$, at altitude h, equals $\rho' v'$, at altitude h, nearly. This relation between the density and velocity of the atmosphere at different levels is known as Egnell's law,[45] determined empirically by himself, as previously by H. H. Clayton,[46] from cloud observations.

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[45] C. R., 136, p. 360, 1903.

[46] *Amer. Met'l Jour.*, 10, p. 177, 1893.

Obviously ρv has a maximum value at that level at which the horizontal pressure gradient is a maximum; that is, at about 8 kilometres above sea level.

Relation of Velocity to Altitude Above 5 Kilometres.—Obviously, if the temperature is constant, as, for simplicity, we may assume it to be,

$$\frac{\rho}{\rho'} = \frac{p}{p'}.$$

But, as already seen, under this condition of constant temperature, through a considerable range of altitude—that is, from below 5 to above 10 kilometres—

$$\frac{p}{p'} = \frac{h'}{h}, \text{ roughly.}$$

Hence,

$$\frac{\rho}{\rho'} = \frac{h'}{h}, \text{ roughly.}$$

But, as explained above, $\rho v = \rho' v'$

Therefore,

$$\frac{v}{v'} = \frac{h}{h'}, \text{ approximately,}$$

or the velocity of the wind through the levels in question is roughly proportional to the altitude.

Above the isothermal level or over the regions between the thermal equator and latitude 50° to 60° the horizontal temperature gradient decreases, and presently even reverses with increase of elevation, as shown by Fig. 43, and therefore the corresponding pressure gradient also decreases, as shown by Fig. 44. Hence, the mass flow, ρv, likewise decreases with elevation above this critical level. Further, the decrease of the horizontal pressure gradient, and consequently of ρv, with altitude in the stratosphere appears usually to be more rapid than that of the density alone, from which it follows that the wind velocity generally must have its maximum value at or below the isothermal level.

Season of Greatest Winds.—From the above discussion it is obvious that the general wind will be swiftest whenever the temperature contrast betwen the air of higher and lower latitudes is greatest. But the temperature of the atmosphere in low latitudes does not change through the year nearly so much as does that of higher latitudes. Hence, the maximum horizontal temperature gradient, and therefore the greatest pressure gradient and strongest winds, must occur during winter.

Latitude of Greatest Winds.—The latitude of strongest winds clearly is that at which the horizontal pressure gradient is greatest. In the northern hemisphere, according to Fig. 43, this occurs in the summer at about latitude 45°. It is obvious, however, since the pressure gradient depends in general upon the latitude rate of temperature change, that the belt of maximum winds must shift more or less from season to season—poleward with the coming of summer, equatorward with the onset of winter.

Hours of Greatest and Least Winds.—On land, but not appreciably at sea, the velocity of the surface wind has a well-defined daily period. Over comparatively level regions it is least, on the average, about sun-up and greatest from 1 to 2 P.M., with a larger change on clear days than on cloudy. It is also most pronounced in summer, when it reaches an average altitude of about 100 metres, and least in winter, when its depth is only about 40 metres.

The physical explanation of this phenomenon was given long ago by Espy. During the night, when there is no vertical convection, surface friction holds the lower air comparatively quiet, while the upper air glides over the lower with but little restraint. During the day, however, and especially during clear, summer days, vertical convection causes the surface layers of air and those directly above to become thoroughly mixed and therefore to have a more or less common velocity, which, obviously, is greater than the undisturbed or night surface velocity, and less than the undisturbed upper layers before their mixture with the lower.

Daily changes of wind velocity also occur on mountain tops, where the maximum is at night and the minimum by day, or just the reverse of the velocity changes that occur near the surface over plains. Three factors, possibly more, combine to produce this result: (*a*) Contraction of the lower air by night, thus bringing air of slightly higher levels, possibly 15 metres (50 feet) or so, and therefore of somewhat greater velocity down to the mountain top. (*b*) The presence by day and absence by night of surface disturbance, due to convection, in the air flowing over the mountain. (*c*) Overflow from the region of maximum expansion to the region of maximum compression. Since the greatest expansion usually occurs at 3 to 4 P.M. and the greatest compression at 5 to 6 A.M., it follows that the overflow will be from west to east, or with the prevailing winds, through the night, and from east to west, or against them, during most of the day; that is, from sun-up to 3 or 4 P.M.

Daily Direction of the Wind.—The average direction of the wind changes slightly during the day, both over plains and on mountain tops, the tendency being for it always to follow the sun, or, rather, the most heated section of the earth. That is, the wind tends to be east during the forenoon, south (in the northern hemisphere) during the early afternoon, and west during the late afternoon and early evening. This does not mean that at each instant the wind really blows directly from the then warmest region, but that the actual changes through the day in the average hourly wind directions can be accounted for by a velocity component away from that region. The whole sequence results from the thermal expansion of the atmosphere (progressive from east to west), which causes an increase of pressure and consequently an outward flow at all levels above the surface. The area covered is so vast that the time involved, only a few hours, is insufficient for the completion of the convection circuit, so that even the surface winds are *away* from the most heated regions, as stated, and not toward them, as in sea and land breezes, for instance. The compensating or return current occurs at night, when the component, outside the tropics at least, is from the higher latitudes. In reality the entire phenomenon is only a diurnal surge, a flux and reflux, of the atmosphere due to diurnal heating and cooling.

Normal State of the Atmosphere.—From the above explanations of the causes of general winds, especially those that pertain to cloud levels, it appears that the normal state of the atmosphere is one of considerable velocity with reference to the surface of the earth. In middle latitudes, at least, this velocity is from west to east more or less along parallels of latitude and so great as nearly to balance the latitudinal pressure gradient due to the zonal distribution of insolation. Calms, therefore, in this region must be regarded as disturbances of the atmosphere, and indeed often are comparatively shallow, with normal winds above.

Equatorial East to West Winds.—East to west winds are quite as general and constant in equatorial regions as are west to east winds in middle latitudes. Along its borders, roughly 30° N. and 30° S., this equatorial belt of east to west winds is very shallow. Toward the equator its thickness increases, as a rule, until it reaches at least the limit of vertical convection. There are, however, great irregularities in these winds, just as in those of higher latitudes on either side of it. But the general conditions are as stated and require explanation.

Conceivably the tidal action of the sun and moon on the atmosphere might set it rotating from east to west. But the barometric amplitudes of the atmospheric tides are very small, only about 0.12 m.m. and 0.027 m.m., due respectively to the sun and the moon.[47] Besides, they have but little phase lag, or follow closely under the disturbing body. Hence the tendency of the tide-producing forces to establish an east to west circulation of the atmosphere must be very small.

The diurnal heating and cooling of the air presumably also tends slightly to produce a planetary circulation, possibly in the same direction as that due to the tidal action, or from east to west. In equatorial regions, and in general wherever and whenever days and nights are approximately equal, the atmosphere is most condensed about daybreak, or, say, at 5,30 A.M., and most expanded at about 3.30 P.M. Hence at such times and places the gradient toward the east is to the pressure gradient toward the west substantially as the greatest and least distances, measured along a parallel, between the meridians of highest and lowest temperature; that is, as 7 to 5. On the other hand, the time of flow along the steeper gradient is to the time along the gentler as 5 to 7. But as the distance through which a given mass is moved, provided it is free to move, is proportional to the product of the force acting by the square of the time, it follows that the diurnal temperature changes, neglecting friction, which indeed may even reverse the sense of motion, should give the atmosphere an east to west velocity whose average magnitude would be determined in part by viscosity. The effect of the double diurnal pressure wave on this velocity is uncertain.

However, this thermal effect on wind velocity, whatever its value, clearly is of secondary importance. Possibly it may have some relation to the unexpected east to west winds, the so-called upper trades, reported in the stratosphere over equatorial regions, but many more observations and a more rigid discussion of the theory of atmospheric circulation would be necessary to settle this interesting question.

The only other obvious cause of east to west and west to east general or planetary winds is interzonal circulation, to which, indeed, they usually are regarded as being entirely due. Heating in equatorial and cooling in polar regions necessarily produce a more or less vigorous interchange of air, but, as already explained, one that is profoundly modified by earth rotation.

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[47] Lamb, *Proc. Roy. Soc.*, A. 84, p. 556, 1910.

Assume, as initial conditions, non-rotation, smoothness of surface, uniformity of surface temperature, and absence of local convection. Let the temperature of the surface and the atmosphere now be decreased in proportion to the distance from the equator. There will be a poleward overflow and an equatorward underflow. Further, if, as assumed, there is no local convection—no intermingling of the air at different levels—the equatorward surface air obviously must remain at the surface throughout its course to lower latitudes and then, after rising in the general, not local, convection, move poleward at the top of the atmosphere. Similarly, any other layer must retain, in its equatorial course, a nearly fixed height above the surface and in its poleward journey a corresponding distance below the top.

As a further modification assume again an initial uniformity of surface temperature, but let the earth and the atmosphere be everywhere rotating at the same rate, so that there shall be no winds of any kind. As before, let the temperature be decreased in proportion to the distance from the equator, but let there be no local convection. Again there would be established an upper poleward and an under equatorward circulation, but the air that started toward either polar region would quickly assume an eastward component, while the under- or counter-current would have a westward component. In the absence of friction or other disturbing factor, the upper air moving under a pressure gradient from lower toward higher latitudes would approach along an asymptotic spiral a certain limiting parallel, where the deflecting force due to its final velocity would equal the pressure gradient across that circle. At the same time the east to west under-current would give a deflective force counter to the equatorward gradient. Hence, perhaps, equilibrium would soon be reached with west to east over winds balancing the poleward pressures and east to west under winds balancing the equatorward pressures, and thus further interzonal circulation prevented.

But surface friction, viscosity, local convection, and other disturbing factors so restrict the approach to equilibrium velocities that interzonal circulation is continuous, though of varying intensity, both local and general. Hence the eastward moving upper air must gradually reach the surface and reach it as an eastward wind. In its subsequent course to lower latitudes it will become a westward wind, as already explained. In general, then, the areas of planetary atmospheric descent are the regions of west to east winds, while the similar areas of ascent are regions of east to west winds. Doubtless, too, these phenomena are accentuated at the surface—that is, the eastward and the westward surface winds are stronger than they otherwise would be—by the intermingling of the air of different levels through innumerable local convections.

What latitude establishes the boundary between the east and west winds? This important question has no answer, not even a theoretical one, unless height is considered. At the surface the boundary is several degrees nearer the equator during winter than in summer, but its average latitude is, roughtly, 30° to 32°. Near its border the east to west winds are very shallow, but in general they increase in depth as the equator is approached until they extend to the limit of vertical convection.

If the temperature distribution were the same along all meridians, and gradually varied from highest at the equator to lowest at the poles, it would seem that the area of ascending air would be substantially the same as the area of descending air (really a trifle larger, because of the higher temperature and consequent greater volume of the ascending air), and therefore that the surface borders between east and west winds would be approximately 30° on either side of the equator. But temperature is not distributed in this ideal way. There are restricted areas which are exceptionally warm, at least during a portion of the year, and others that are exceptionally cold, hence one would expect the area of ascent to be only roughly equal to the area of descent, and therefore the boundaries in question to be, as they are, only approximately at latitudes 30° N. and 30° S.

The velocity of the west to east winds of middle and higher latitudes and the velocities of east to west winds of equatorial regions obviously depend ultimately upon the rate of interzonal circulation. If this circulation were zero, surface friction, facilitated by local vertical convections, soon would greatly diminish and finally eliminate any cross-meridian velocity that originally might obtain. On the other hand, an extremely vigorous interzonal circulation would lead to violent east to west winds, partly because velocity is not altered by mere deflection and partly because there would then be less time for the latitude (conservation of area) effects on the velocity to be minimized by convectional turbulence—the total number of such disturbances becoming larger and their cumulative effects therefore greater with increase of time. Hence the moderate east winds of equatorial regions and west winds of higher latitudes that actually exist are due to the fact that the interzonal circulation itself is moderate—being largely held in check, as already explained, by the automatic formation of gradient winds in the free atmosphere which roughly follow parallels of latitude.

It appears, then, that the temperature gradient, directed in general from the equatorial toward the polar regions, establishes an upper pressure gradient in the same direction and a lower in the opposite direction; that in the absence of friction or other disturbance these pressures would produce east to west and west to east gradient winds with but little or no interzonal circulation; that as the winds actually are more or less checked by surface friction, turbulence, convection, etc., they fail to attain full gradient velocities, and therefore cross the isobars at a small angle, except near the surface, where this angle is much larger, and thus maintain a correspondingly vigorous interzonal circulation even in the absence of cyclones and anticyclones; that the actual west to east winds of the middle and higher latitudes and the east to west winds of equatorial regions are due chiefly to their approach to gradient directions, and, finally, that the strength of any steady wind is proportional, approximately, to the gradient pressure, and its direction substantially normal thereto.

Probable Interzonal Circulation of the Stratosphere.—The primary circulation just explained involves all the atmosphere from the surface of the earth up to at least the highest cloud levels, but there is reason to believe that it does not extend to the greatest altitudes. Indeed, it appears probable that far above the uppermost clouds there may be another primary or fundamental circulation in reverse direction to that of the lower. This inference is based on the fact that the stratosphere is so much warmer in high than in low latitudes that seemingly there must be an overflow of air from the former to the latter and a corresponding return; that is, a primary circulation in the stratosphere in which the upper branch is from the polar (in this case warmer) toward the equatorial (in this case colder) regions and the under from the equatorial toward the polar regions, with, of course, longitudinal components in each due to the earth's rotation. In a sense the upper circulation, if it exists as inferred, is the mirror image of the lower, though more regular.

In addition to the primary circulation or circulations of the atmosphere as a whole, there are several secondary circulations or wind systems of magnitude sufficient to bring them markedly under the influence of the earth's rotation. It will be convenient next to consider some of the more important of these winds.

Chapter IX.

ATMOSPHERIC CIRCULATION (*continued*).

Winds Due to Widespread Heating and Cooling (continued).

MONSOONS.

Summer monsoons and winter monsoons, for convenience discussed under the same head, bear the same relation to summer and winter that sea breezes and land breezes bear to day and night. It is the temperature contrast between land and water that establishes the circulation that manifests itself on the surface as a sea or land breeze in the one case and as a seasonal or monsoon wind in the other. The direction of the surface wind in either case is always from the cooler toward the warmer of the adjacent regions, from the ocean toward the land by day as a sea breeze and during the warmer season as a summer monsoon; from the land toward the ocean by night as a land breeze and during the colder season as a winter monsoon. Hence monsoons may be regarded as sea and land breezes of seasonal duration, and might very well be classed with the latter under some common appropriate caption. However, because of the immense areas involved, it cannot be said of them, as of sea and land breezes, that they are caused by mere local temperature differences. Besides, the duration of a land or sea breeze is so brief that it covers only a narrow strip along the coast, as already explained, while the monsoon winds extend far from the coast, both inland and to sea and the directions of the former, since their paths are always short, are but little affected by the rotation of the earth, while the courses of the second are greatly modified by this important factor.

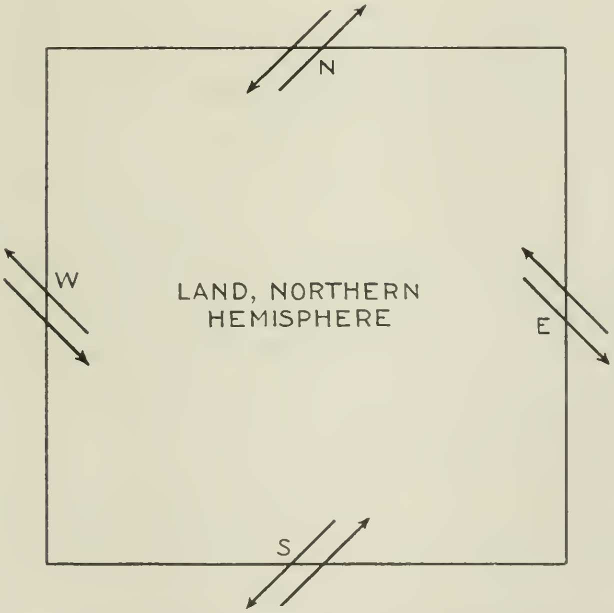
The prevailing directions of monsoon winds, except where distinctly modified by the general circulation, are given by the following table and by Figs. 45 and 46:

Direction of Monsoon Winds

Hemisphere	Season	Land south	Land west	Land north	Land east
Northern	Summer	N. E.	S. E.	S. W.	N. W.
	Winter	S. W.	N. W.	N. E.	S. E.
Southern	Summer	N. W.	N. E.	S. E.	S. W.
	Winter	S. E.	S. W.	N. W.	N. E.

Since monsoons depend upon seasonal temperature contrasts between land and water, it is obvious that winds of this class must be most pronounced where such contrasts are greatest—that is, in temperate regions—and least developed where the temperature contrasts are smallest—that is, in equatorial and polar regions. It is even possible for secondary monsoons to develop, or for a monsoon to occur within a monsoon. This merely requires a

FIG. 45.

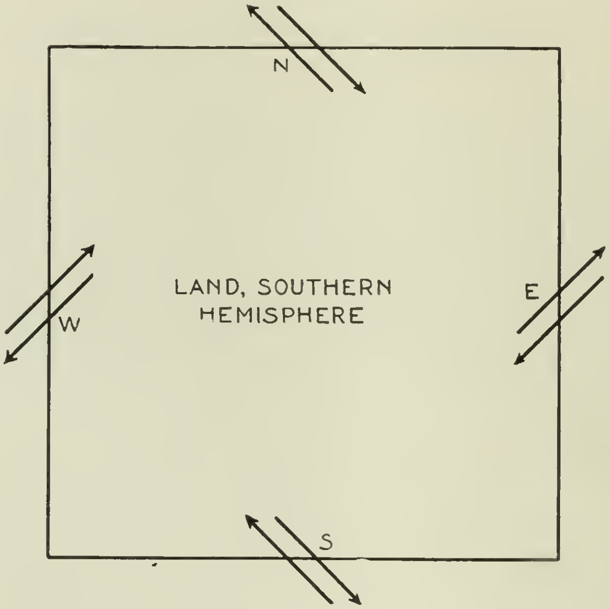


Prevailing directions of monsoon winds, northern hemisphere.

favorably situated inland sea, such as the Caspian. In such cases monsoons or seasonal winds prevail between the inland sea and the surrounding land, and in turn between the continent as a whole and the adjacent oceans, just as, and for the same reason that on a still greater scale, there is a constant circulation between the perpetually warm equatorial regions and those about the poles that are continually cold.

Another comparison between these several winds, the semi-daily (land and sea breeze), semi-annual (monsoon), and perpetual (interzonal), that is interesting and instructive concerns their depth. As already stated, the land and sea breezes seldom reach greater depths than 100 to 500 metres; the winter monsoon of India has a depth, roughly, of 2000 metres, and the summer monsoon 5000 metres; while the general or interzonal circulation involves the whole of the troposphere with a depth of 10 to 12 kilometres, and probably also, though perhaps to a less vigorous degree, even the stratosphere.

Fig. 46.



Prevailing directions of monsoon winds, southern hemisphere.

If the term monsoon be extended, as it properly may, to include all winds whose prevailing directions and velocities undergo distinct alterations as a result of seasonal changes in temperature, it clearly follows that this class of winds is well nigh universal. Nevertheless, it is generally thought of in connection with only those places where it is most strongly developed, and especially where the seasonal winds are more or less oppositely directed. Among these places are: India (Indian monsoons are the most pronounced of all and have been most fully studied), China, the Caspian Sea, Australia, and portions of Africa.

In the United States the chief monsoon effects are in the eastern portion, where the prevailing winds are northwest in winter and southwest in summer, and in Texas, where the prevailing winds are also northwest in winter but southeast in summer.

TRADE WINDS.

As previously stated, in equatorial ocean regions, or, roughly, over the oceans between latitudes 30° N. and 30° S., the winds usually have an east-to-west component. In the northern hemisphere they blow rather constantly from the northeast, becoming east-northeast and finally nearly east winds as the equator is approached. Similarly, in the southern hemisphere, starting from the southeast, they gradually back through east-southeast to nearly east. In each case they blow " trade "; that is, in a fixed or nearly fixed direction. It is because of this steadiness of direction and not because of any relation they may have to the paths of commerce that they are called trade winds. Along each border of this belt, or along both the northern and southern horse latitudes, calms are frequent, while such winds as do occur generally are light and variable in direction. Besides, the barometric pressure is high, humidity low, and sky clear. Hence it generally is inferred that throughout the horse latitudes the air is descending. This evidence, however, as applied to places other than the centres of maximum pressure is not quite conclusive—it only shows that the air is not ascending.

Another narrow belt of calms or light variable winds, known as the region of the doldrums, approximately follows the equator (more exactly the thermal equator), where the two systems of trade winds, the northern and the southern, come together. Here, however, the barometric pressure is low, humidity high, and skies often filled with cumulus and other clouds that give conclusive proof of strong ascending currents.

Trade winds in the sense here used—that is nearly constant winds blowing in a westerly direction—do not occur on land except along coasts and over islands. Besides being well-nigh peculiar to the oceans, they are even different from ocean to ocean, and also, since they tend to follow the thermal equator, somewhat different in latitude and intensity from season to season.

According to Shaw the average velocities of the Atlantic trade winds are as follows:

Trade-wind Velocities, Atlantic Ocean.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	
N. E. trade...	11.9	13.0	13.5	13.4	12.3	11.4	10.3	8.3	9.6	7.4	9.8	11.6	10.5	miles hour
N. E. trade...	14.1	13.0	13.0	12.1	11.0	12.1	12.1	15.0	17.0	15.0	16.1	15.0	13.9	miles hour

From this it appears that the trades are strongest during the winter when their counterpart, the system of westerly winds of higher latitudes, is strongest; and weakest during the summer when their counterpart is weakest. It also appears that the south-trades, or those pertaining to the southern hemisphere, are about one-third stronger than the northeast trades, due probably to the greater extent of the southern oceans and consequent less surface friction—the same reason, doubtless, that the westerly winds of the southern hemisphere are stronger, on the average, than the westerlies of the northern hemisphere.

The trade winds of the Pacific Ocean are weaker than those of the Atlantic and not so constant in direction. On the Indian Ocean the trades are confined to the southern hemisphere. North of the equator the winds of this ocean, being controlled by the adjacent continent, are distinctly of the monsoon type.

The seasonal shifting in latitude of the trade regions and belt of doldrums is shown by the following table, copied from Hann's Lehrbuch, 3d edition, p. 463:

Seasonal Latitude Limits of Trade Winds and Doldrums.

	March		September	
	Atlantic	Pacific	Atlantic	Pacific
N. E. trade.	26°–3°N	25°–5°N.	25°–11°N.	30°–10°N.
Doldrums...	3°N.–Equator	5°–3°N.	11°– 3°N.	10°– 7°N.
S. E. trade..	Equator–26°S.	3°N.–28°S.	3°N.–25°S.	7°N.–20°S.

ANTITRADE WINDS.

As the heated and expanded air of equatorial regions overflows to higher latitudes it necessarily is deflected by the rotation of the earth. That portion which goes north changes from an east wind near the equator to a southeast, south, southwest, and, finally, at about latitude 35° N., a more nearly west wind. Similarly, that portion which goes south becomes northeast, north, northwest, and, finally, at about latitude 30° S. a more nearly west wind.

At great altitudes, 10 to 15 kilometres, the east-to-west velocity near the equator is, roughly, 36 metres per second (80 miles per hour). Hence its west-to-east velocity around the axis of the earth is about 428 metres per second (957 miles per hour). As this air, assuming it to start from the equator and neglecting viscosity effects, moves to higher latitudes its west-to-east velocity must so increase, according to the law of the conservation of areas, that at about 16° N. or S. its angular velocity will be the same as that of the earth, and itself, therefore, be moving only poleward in the plane of the meridian. The exact latitude, however, at which the antitrades move directly poleward depends upon the position of the thermal equator and therefore varies with the seasons. Thus during August and September, when the centre of the doldrums is, roughly, 8° N., the inflection of the northern antitrades occurs somewhere between latitudes 20° N. and 25° N. At other seasons, because the doldrums are then nearer the equator, the place of inflection is also less removed. Beyond the turning point, wherever that may be, these upper or antitrade winds become westerly, and, except as modified by local disturbances, tend, as previously explained, to reach, under the influence of the poleward pressure, a limiting or gradient velocity and to follow parallels of latitude. However, there are innumerable disturbances, mainly due to the distribution of land and water, that cause constant and abundant interzonal circulation which feeds and indefinitely maintains the antitrade wind portion of the general or planetary atmospheric circulation.

The height of the antitrades (depth of the trades) is greatest, at any given place, during summer and least during winter. It also decreases with latitude, becoming zero, on the average, at about 30° N. and S. Thus during winter their height over Cuba, 22° N., is about 3.5 kilometres; over Jamaica, 17° N., 6.5 kilometres; over Trinidad, 12° N., 8 kilometres, and over Hawaii, 19° 30′ N., about 3 kilometres. But whatever their height it is always the same as the depth of the trades of which they are but the overhead continuation. Indeed, the trade winds as they approach the equator ascend and gradually flow off poleward, thus producing in each hemisphere a great antitrade branch of the general circulation, which in turn becomes the westerlies of higher latitudes. These, in their turn, are confused by storms and other local disturbances, but after few or many vicissitudes, as circumstances may determine, ultimately return to a similar starting-point, only to begin another of their endless cyclic journeys through trades, antitrades, westerlies, and the innumerable secondary winds such a course implies.

TROPICAL CYCLONES.

A tropical cyclone—the cyclone of the Indian Seas, the hurricane of the West Indies and South Pacific, and the typhoon of the West Pacific and China Sea—consists of a vast whirl of rapidly moving air currents surrounding a calm and relatively small centre or vortex.

Distinction Between Tropical and Extra-tropical Cyclones.—Although tropical and extra-tropical cyclones have many similarities, such as low-pressure centres, abundant precipitation, same instantaneous wind directions, and the like, and although it may be impossible to say just when a tropical cyclone on its way to higher latitudes becomes extratropical in character, nevertheless they usually differ from each other in several important respects. Among these differences are: (*a*) The isobars of the tropical cyclone generally are more symmetrical and more nearly circular than those of the extra-tropical. (*b*) The temperature distribution around the vortex of the tropical cyclone is practically the same in every direction, while about the extra-tropical it is very different. (*c*) In tropical cyclones rains are torrential and more or less equally distributed on all sides of the centre; in the extra-tropical rains usually are much lighter and very unequal in different quadrants. (*d*) Tropical cyclones usually have calm rainless centres 10 to 50 kilometres (6 to 31 miles) or more in diameter, while the extra-tropical rarely show this characteristic whirl phenomenon. (*e*) Tropical cyclones are most frequent during summer of the hemisphere in which they occur, while the extra-tropical are strongest and most numerous during winter. (*f*) Tropical cyclones often move to higher latitudes, where they assume, more or less completely, characteristics of the extra-tropical; the extra-tropical, on the other hand, never invade the region of the tropical nor assume its distinctive characteristics. (*g*) The pressure-drop of the tropical cyclone generally begins with the winds; in the extra-tropical it usually begins much sooner. (*h*) The tropical cyclone has no anticyclone companion; the extra-tropical usually has—to the west.

Place of Occurrence.—Tropical cyclones occur over the warmer portions of all oceans except, possibly, the South Atlantic. They are most numerous, however, in the west Atlantic (including the Gulf of Mexico), Bay or Sea of Bengal, and west Pacific (including the China Sea), where their annual frequencies are, roughly, about 4, 8 and 24 respectively. They seldom originate closer than 5° or 6° to the equator but most frequently between latitudes 10° and 20.° In fact, they seem to originate almost entirely along the belt of doldrums, and therefore, since this belt follows the sun, to appear at higher latitudes during summer and lower, or not at all, during winter.

Size and Shape of Storm.—The diameter of the tropical cyclone varies greatly. Near their origin some may be no more than 80 kilometres (50 miles) across, while others, when well developed, may have diameters of 300 to 1500 kilometres (187 to 932 miles). The clouded area incident to typhoons, always much more extensive than the surface storm, may be even 3000 kilometres (1864 miles) across.

The shape of the storm, as given by the isobars, appears usually to be that of an ellipse whose diameters are to each other, roughly, as 2 to 3, with the longer axis in the direction of travel.

Direction of Wind.—The surface direction of the wind is spirally in at an angle of 30 degrees, roughly, to the isobars, counter-clockwise in the northern hemisphere, clockwise in the southern. At an elevation of only 700 to 800 metres the inflow is said to cease, and above this level the circulation is outward. These horizontal motions necessitate a correspondingly strong upward component around the vortex or inner portion of the storm, and a slower downward component over a much greater surrounding area.

Velocity of Wind.—The velocity of the wind in a tropical cyclone also varies greatly from one storm to another, and even more from one to another portion of the same storm. Near the centre, or within the eye of the storm, which may have any diameter from 8 to 50 kilometres (5 to 31 miles) or more, the wind is very light and the sky clear or only partially covered with high clouds. Away from this centre, especially on the poleward side, the winds often reach destructive velocities of 40 to 50 and even 60 metres per second (90 to 112 or even 134 miles per hour), but decrease in violence rather rapidly with increase of distance from the centre; dropping to only moderate winds of 50 to 60 kilometres (31 to 37 miles) per hour at a distance of, say, 300 kilometres (187 miles).

Direction of Travel.—Tropical cyclones of the northern hemisphere first move west, then usually northwest. Many turn north at latitude 20° to 25°, roughly, and finally move away to the northeast. In the southern hemisphere the corresponding directions of travel of the tropical cyclone are: West, southwest, south, and, finally, southeast.

Velocity of Travel.—The velocity with which tropical cyclones travel varies from almost zero in certain cases, especially at or near the place of inflection when this happens to be abrupt, to perhaps 800 kilometres (497 miles) per day. Over the Bay of Bengal, Arabian Sea, and China Sea the velocity averages about 320 kilometres (199 miles) per day. Over the south Indian Ocean the velocity ranges from 80 to 320 kilometres (50 to 199 miles) per day. Over the west Atlantic the average velocity before and during recurvature is about 420 kilometres (260 miles) per day, but after recurvature—that is, when moving northeast over middle latitudes—about 640 kilometres (398 miles) per day.

Origin and Mainténance.—Since tropical cyclones originate in a belt or region of doldrums where convectional rains are frequent and heavy, and since they rarely occur closer than 5° or 6° of the equator, it follows that both vertical convection and earth rotation are essential to their genesis.

The atmosphere of a doldrum belt becomes very warm and humid, and therefore frequently is in a state of vertical convection. The upward branches of this convection are nearly always limited to very restricted areas, where they break through, as it were, and often give rise to local thunderstorms. Occasionally, however, heating and expansion must take place more or less uniformly over a comparatively extended region. So long as the upward current is gentle and restricted to a small area, the compensating inflow from the sides is also gentle and can produce only a cumulus cloud and perhaps a thunderstorm. In the event that such a storm is formed, the inflowing counter-current to the ascending warm air is replaced by an equivalent column or sheet of descending cold air immediately to the rear. That is, the loss of warm surface air is compensated by a similarly concentrated and vigorous downflow of cold upper air. Hence, rotary circulation since it depends upon horizontal inflow from all, or at least several, sides, is not possible in the case of ordinary thunderstorms, whatever their location.

On the other hand, an approximately equal expansion of air over a relatively large area, whether caused by an increase of temperature, or vapor density, or by both, must lead to an overflow above and a corresponding surface inflow around the outer borders.

Obviously the rate of volume overflow at any time is proportional to the area in question, while the corresponding inflow is proportional to the boundary multiplied by the average normal component of the wind. If the area is circular with radius R, it follows that the rate of outflow above is proportional to πR^2, and the rate of inflow below to $2\pi RV_n$, in which V_n is the average radially inward component of the wind at the distance R from the centre. But as the two currents compensate each other except as modified by precipitation, explained below, it follows that V_n, other things being equal, is proportional to R. Hence, when the area involved is rather large, 100 miles, say, in diameter, the relatively shallow and spirally moving compensating or return current may become very perceptible. This at once feeds the entire rising column with excessively humid air that renders it an even better absorber than before of both insolation and terrestrial radiation and increases its rate of expansion, thus initiating, perhaps, a widespread condensation. If so, the latent heat thus set free, while it does not actually raise the temperature of the air, reduces the rate of adiabetic cooling from approximately 1° C. to about 0.4° per 100 metres increase of elevation, and thereby establishes within the rising column temperatures distinctly higher than those of the surrounding air at the same level. In this way the circulation is accelerated, and thereby the rate of condensation and freeing of latent heat increased until, through growth of size, restricted supply of water vapor, and other causes, a limiting, somewhat steady, state is attained.

When the conditions here described occur at some distance from the equator the rotation of the earth deflects the inflowing air and establishes a rotation around the region of lowest pressure—an effect all the more likely to occur, and to an accentuated extent, when the existing convection takes place along the doldrum boundary between the rather oppositely directed (not opposing) trade winds, the one from higher latitudes, the other from across the equator. But whatever the radius of curvature, the angular momentum remains constant—the law of the conservation of areas obtains—except as modified by friction and viscosity, and therefore, since surface-drag is effective at but small elevations, the atmosphere at only 100 to 200 metres above the water may, as it moves inward, soon reach that velocity at which its deflective force is equal to the horizontal pressure gradient. When such velocity is reached, as it obviously may be at any appreciable altitude, inflow at that place necessarily ceases. Near the water, however, this limiting velocity is prevented by surface friction. Hence, as soon as the whirl is well established, it must be fed almost exclusively by the lowest and therefore most humid air. In this way a maximum amount of precipitation, and, through it, a maximum amount of thermal energy, is secured—a condition important to the maintenance of the tropical cyclone, as is evident from the fact that it tends to go to pieces over dry land, especially before it has recurved and become essentially extra-tropical.

Of course, similar atmospheric expansions may, and doubtless do, occur in the doldrums when they are on or very close to the equator, but in this case a whirl is impossible, and therefore a low so initiated will soon fill by gentle, somewhat radial, winds from all sides and at considerable altitudes, or, at most, mere local thunderstorms will develop.

From the above it is evident that the seat, so to speak, of the tropical cyclone is where the sustaining energy is supplied; that is, where condensation is taking place. Hence the movement of the air at this level, and not at the surface, determines the course of the storm, and even carries it athwart shallow surface winds.

(*To be continued.*)

THE VERTICAL DISTRIBUTION OF DISSOLVED OXYGEN AND THE PRECIPITATION BY SALT WATER IN CERTAIN TIDAL AREAS.*

BY

J. W. SALE AND W. W. SKINNER.

Birge and Juday[1] have shown that dissolved oxygen is deficient in the lower layers of water of 129 inland lakes of Wisconsin, due to thermal stratification of the water and subsequent depletion of the oxygen in the colder layers by the process of respiration of plants and animals, by the direct oxidation of dead organic matter, and by the decomposition which results from the action of bacteria.

Data obtained by the Water Laboratory of this Bureau show that less dissolved oxygen is present in the water near the bottom of the Potomac Estuary and of portions of the Chesapeake Bay than in the surface water, apparently due to the under-run of salt water present in those waters and the subsequent depletion of the oxygen in the lower layers as indicated by Birge and Juday.

Other data obtained show that maximum turbidity of two tidal rivers is attained in the regions where salt water first appears.

The two phenomena of depleted dissolved oxygen content and of maximum turbidity at the junction of fresh and salt water are related in that the sedimentation caused by the salt water is a contributing factor in the depletion of the oxygen of the lower layers of water.

These data are of particular interest at this time because of the possible relation which the dissolved oxygen content bears to the mortality of fish and shellfish, reported as occurring at the mouth of the Potomac and of other rivers flowing into Chesapeake Bay and in other tidal waters. It is thought that the dissolved oxygen content of those waters may have a profound influence on fish life, particularly on the migration of fish in those regions.

Helland-Hansen[2] noted a deficiency of oxygen in the lower water of some oyster ponds situated in Norwegian fjords. These ponds were connected with the main bodies of water in the fjords only during unusually high tides. The deficiency of dissolved oxygen threatened the destruction of the oysters.

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* Contribution from the Water Laboratory, Bureau of Chemistry, U. S. Department of Agriculture. Communicated by Doctor Skinner.

The content of chlorin, turbidity, and dissolved oxygen of about 275 surface and deep samples collected from the lower Potomac River, Maryland, the Maurice River, New Jersey, the

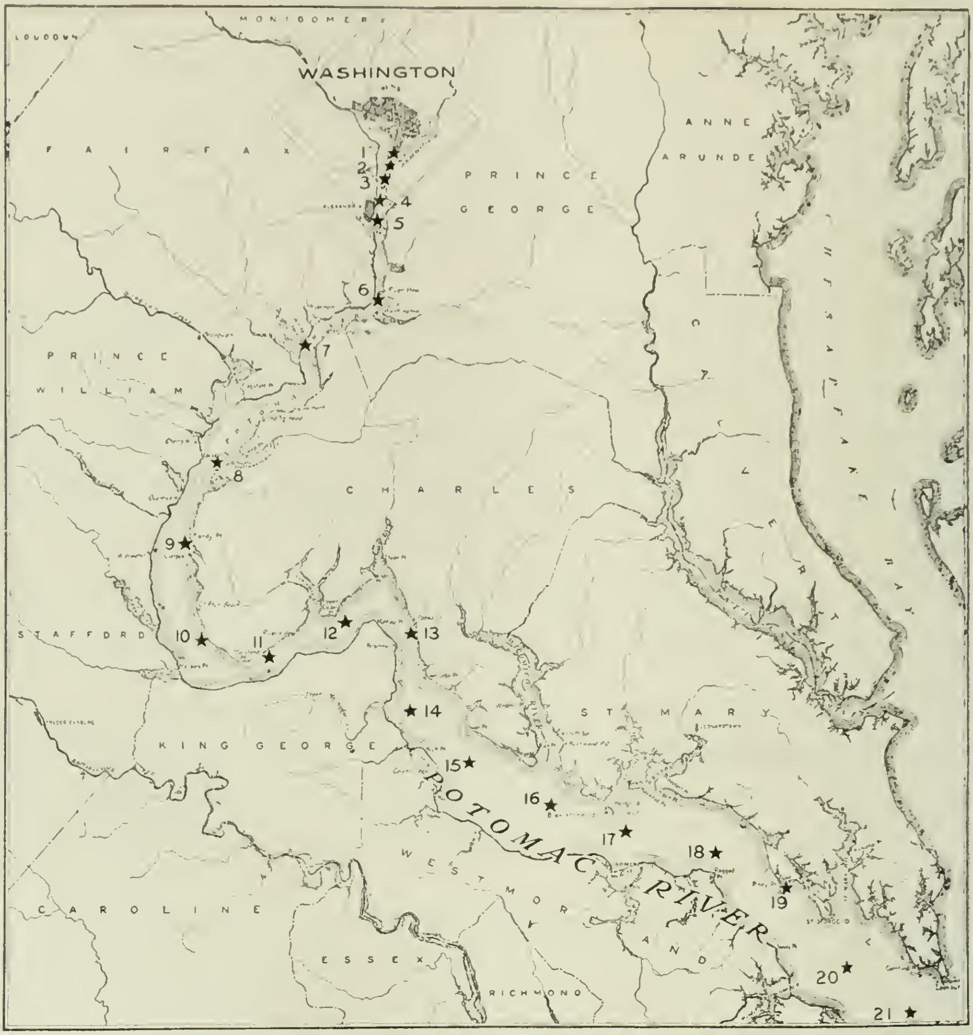

Fig. 1.—Map of Potomac Estuary, showing location of sampling stations.

Approximate depth in feet at Sampling Stations in lower Potomac River:

No. 1, 27; No. 2, 33; No. 3, 27; No. 4, 31; No. 5, 33;
No. 6, 20; No. 7, 34; No. 8, 33; No. 9, 30; No. 10, 27;
No. 11, 24; No. 12, 45; No. 13, 32; No. 14, 34; No. 15, 27;
No. 16, 43; No. 17, 27; No. 18, 30; No. 19, 75; No. 20, 75;
No. 21, 75.

Chesapeake and the Delaware Bays have been plotted for purposes of comparison, the mutual relations being shown clearly in the accompanying curves. Seasonal temperature and chlorin curves for the lower Potomac River are contained in Figs. 8

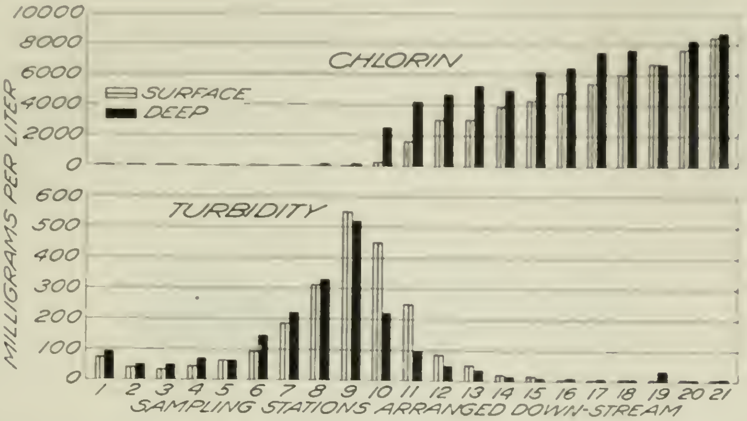

FIG. 2.—Lower Potomac River, Washington, D. C., to Point Lookout, March 11–13, 1912.

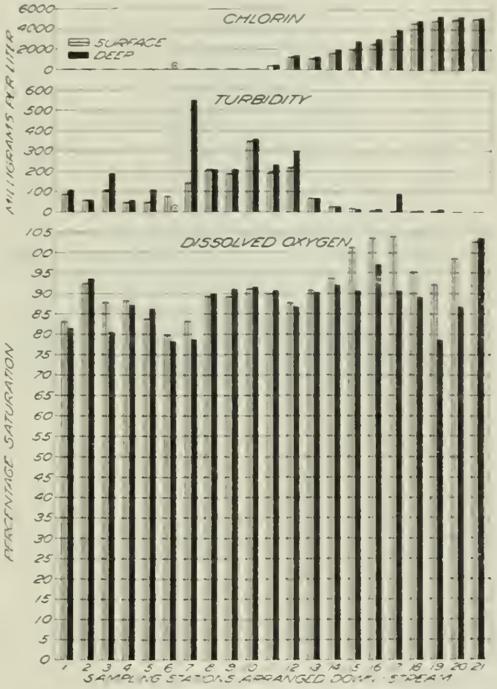

FIG. 3.—Lower Potomac River, Washington, D. C., to Point Lookout, April 29–May 9, 1912.

and 9. All curves have been arranged to extend down stream or down the bay. The locations of the sampling stations in the lower Potomac River are shown on the map, Fig. 1. The so-called surface samples were collected about one foot below the surface and the deep samples about three feet from the bottom. The methods of examination used were those recommended by the A. O. A. C., published in the *Journal of the A. O. A. C.*, vol. 2, No. 4.

The under-run of salt water in the Potomac Estuary and Chesapeake Bay is shown by a comparison of the chlorin curves for the surface and deep samples (Figs. 2, 3, 4, 5, 6, 7 and 10). It will be noted that the two layers of water of different specific gravity are quite distinct in the salt-water section of the river. In the Maurice River the under-run of salt water, while present, is not so noticeable, the mixing of the water in that locality being fairly complete when samples were collected in November, 1912 (see chlorin curves, Fig. 11).

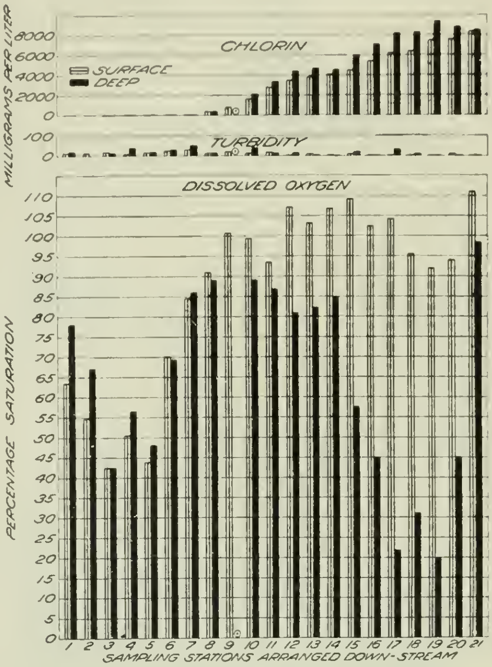

Fig. 4.—Lower Potomac River, Washington, D. C., to Point Lookout, September 21, 22, 1912.

A comparison of the turbidity curves with the chlorin curves for both the Potomac and Maurice Rivers shows that, with two exceptions, which are evidently abnormal (Figs. 3 and 5), maximum turbidity is attained at the station where the content of chlorin begins to increase (Figs. 2, 4, 6, 7, 11). This relation is most evident when the fresh water of the rivers is quite turbid (Figs. 2, 3, 7), and indicates a precipitation of matter which had been dissolved in the fresh river water. A noticeable feature of the turbidity curves is that the rise to a maximum and the fall take place within a few sampling stations above and below the rise in salinity.

Cummings[3] has stated that the area from Indian Head to Maryland Point in the lower Potomac River is a great natural basin in which sedimentation is caused by the irregularity in velocity and direction of current and by the admixture of enormous volumes of sea-water, with its inability to carry large proportions of suspended matter.

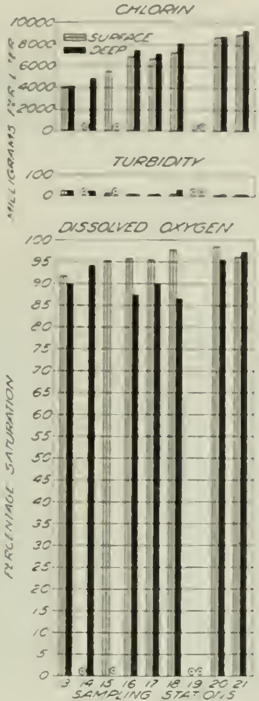

FIG. 5.—Lower Potomac River, off Pope's Creek, Maryland, to Point Lookout, October 24, 25, 1912.

These conclusions are confirmed by the data expressed in graphic form in Figs. 2, 3, 4, 6, 7.

An inspection of Chart No. 559 of the United States Coast and Geodetic Survey for the section of the lower Potomac River extending from lower Cedar Point to Mattawoman Creek shows an extensive series of flats between Maryland and Sandy Points, which it is believed have been formed by the precipitating and coalescing action of the salt water and subsequent sedimentation of the suspended matter. The channel of the river for a considerable distance opposite these flats is very narrow. For instance, off Douglass Point the river is about 2.7 miles wide, while the channel of the river is only about one-tenth of this distance, or 0.27 mile.

A study of the relations of the dissolved oxygen curves to the chlorin curves shows that when an under-run of salt water is present the dissolved oxygen curves for the deep samples are considerably lower than the curves for the surface samples, showing less dissolved oxygen in the deep samples than in the surface samples. When an under-run of salt water is absent (that is, when the water is practically uniform in composition), the dissolved oxygen curves are closer together, or the deep samples may contain even more dissolved oxygen than the surface samples. For example, in September, 1912 (Fig. 4), the curves for surface and deep samples are relatively close together in that area of the lower Potomac River extending from Stations 1 to 7, while from Stations 8 to 21 they are widely separated. The chlorin curves show that above Station 7 the water was uniform in composition, while below Station 7 there was a marked under-run of salt water.

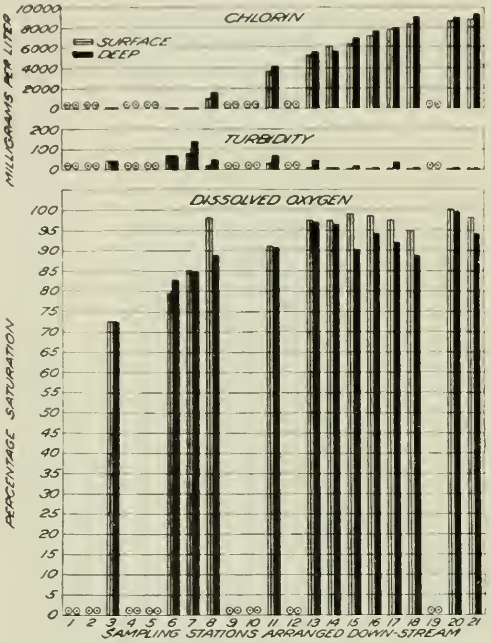

Fig. 6.—Lower Potomac River, vicinity of sewage outlet, to Point Lookout, December 3, 4, 1912.

It is probable that the under-run of salt water in the Potomac Estuary and in Chesapeake Bay interferes with the distribution of oxygen by reason of its greater specific gravity, which keeps the denser water persistently on the bottom, thus hindering the mechanical mixing of the water by tides, winds, etc.

This stratification, due to concentration, is very persistent in the Potomac Estuary. It was present without exception each time samples were collected from that area under widely varying conditions of the weather. For example, on October 24, 1912, the wind was very high and the water of the estuary was very rough. For several days prior to this date a strong northwest wind had lowered the level of the water appreciably. Nevertheless, this extreme agitation of the water of the estuary did not effect a uniform mixing (Fig. 5). Also, a few days prior to April 15, 1913, heavy rains occurred, following a rather dry season of about a month. The flood at this time pushed back the incoming salt water to Station 11, between Maryland Point and Riverside, some thirty miles below Station 7, off Whitestone Point, which was the upper limit of the salt water in September and December, 1912 (Figs. 4, 6, and 7). It will be noted that the under-run of salt water, together with the depleted oxygen content in the lower layer of water, persisted under these conditions.

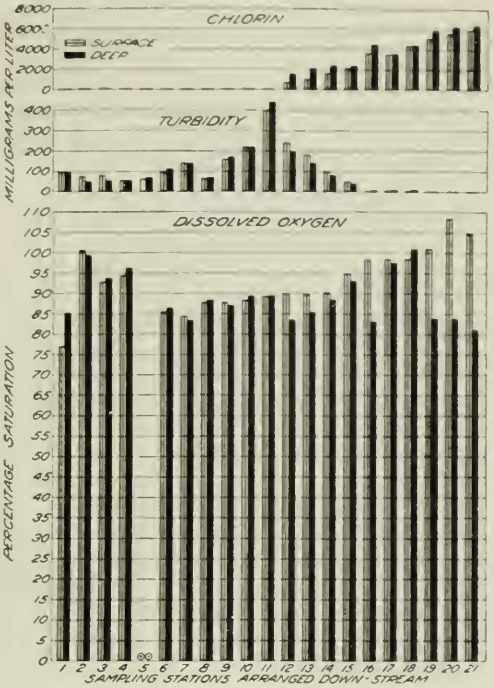

FIG. 7.—Lower Potomac River, Washington, D. C., to Point Lookout, April 15-17, 1913.

The dissolved oxygen content has been expressed in percentage saturation. The lower curves for dissolved oxygen in the deep samples, therefore, represent an actual consumption of oxygen.

Since dissolved oxygen is consumed chiefly by the decomposition of inanimate organic matter, the stratum of water nearest to the decaying organic matter would suffer the greatest depletion of oxygen. The decomposable organic matter may be obtained from several sources. During high water in the river, a portion of the material which has been deposited by the process of salt-water precipitation referred to above, and by sedimentation in a rather restricted area, is stirred up and swept down stream with the current, to again gradually settle out over a larger area of bottom or to be collected in other portions of the river, favored because of the contour of the bottom or by the currents. Another

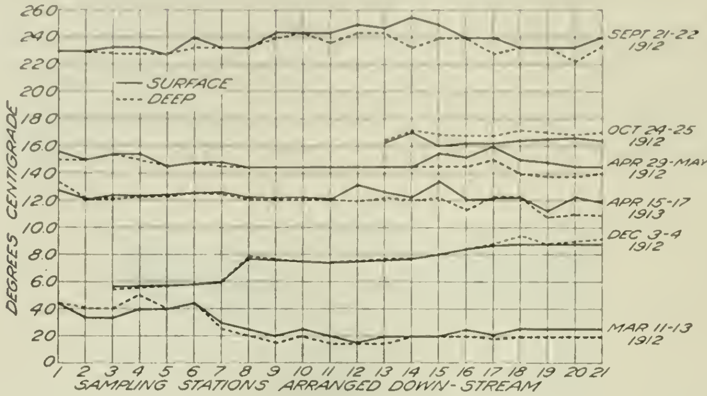

FIG. 8.—Lower Potomac River, Washington, D. C., to Point Lookout. Seasonal variations in temperature.

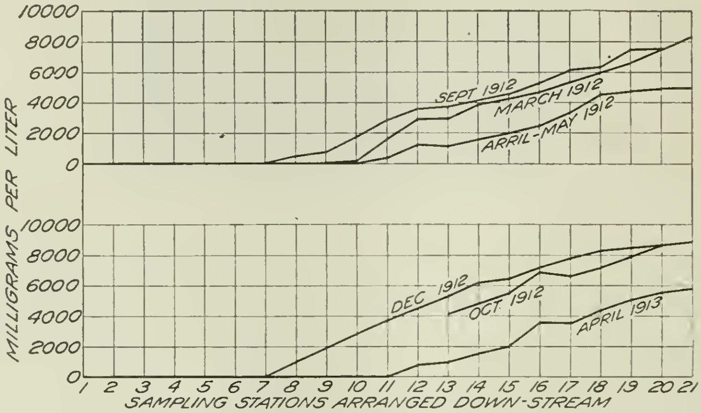

FIG. 9.—Potomac River chlorin curves, March, April, September, October, December, 1912, and April, 1913. (Surface samples.)

source of decomposable matter is plankton forms, which die, settle to the bottom, and decompose. Purdy[4] has shown that the volume of plankton in the Potomac River in the vicinity of Point Lookout is greater than in any other portion of the lower river.

Broken-down, submerged plants, leaves, elutriated soil, and other débris which are carried into the estuary and bay by

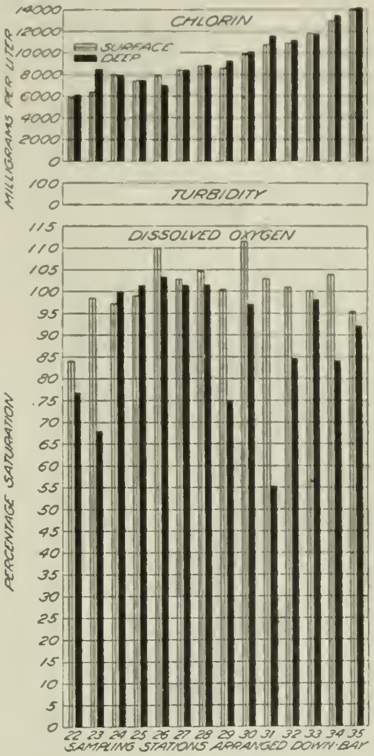

FIG. 10.—Chesapeake Bay, Annapolis to Fortress Monroe, September 20 and October 3, 1912.

Sampling Station, No.	Date collected	Depth, feet	Location
22	10–3–12	50	Off Annapolis.
23	10–3–12	50	One mile south Kent Island Light.
24	10–3–12	50	Off mouth Great Choptank River.
25	10–3–12	40	About two miles above Cove Point.
26	10–3–12	30	Off mouth Patuxent River.
27	10–3–12	30	Just above Point No Point Light.
28	10–3–12	24	Off Point Lookout.
29	9–20–12	60	4¼ miles off Smith Point Light.
30	9–20–12	30	9 miles off mouth Great Wicomico River.
31	9–20–12	40	10 miles off mouth Rappahannock River.
32	9–20–12	35	6 miles off shore, south of Piankatank River.
33	9–20–12	35	4 miles off Mobjack Bay.
34	9–20–12	30	13 miles off mouth of York River.
35	9–20–12	30	8 miles off Buckroe Beach.

numerous tributaries also furnish their quota of decomposable matter.

A certain amount of dissolved oxygen is consumed in the life-processes of marine organisms.

The dissolved oxygen, therefore, in the dense bottom layer of water is depleted chiefly by the decomposition of dead vegetable

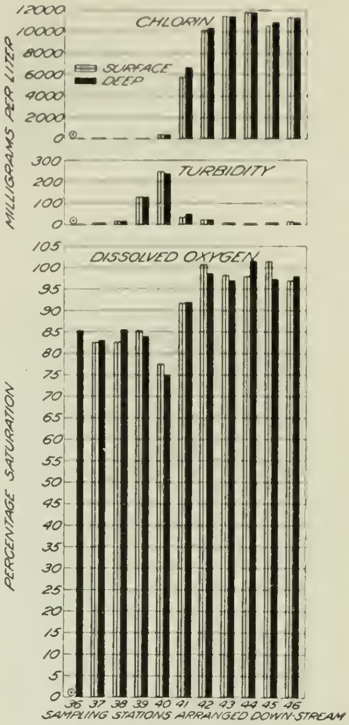

FIG. 11.—Maurice River and Delaware Bay, Millville to Egg Island Light, November 19, 20, 1912.

Sampling Station, No.	Date collected	Depth, feet	Location
36	11–19–12	12	Maurice River, at Millville.
37	11–19–12	12	Maurice River, at Kees Landing.
38	11–19–12	24	Maurice River, off Buckshuten.
39	11–19–12	26	Maurice River, at Morristown Bridge.
40	11–19–12	33	Maurice River, ¼ mile below Menhaden.
41	11–19–12	14	Maurice River, at mouth.
42	11–20–12	11	Delaware Bay, 5 miles S. by E. of East Point Light.
43	11–20–12	12	Delaware Bay, 5 miles S. of East Point Light.
44	11–20–12	13	Delaware Bay, 1½ miles S. W. Egg Island Light.
45	11–20–12	18	Delaware Bay, just outside False Egg Island.
46	11–20–12	9	Delaware Bay, about ⅓ mile off Egg Island Light.

and animal matter gathered from various sources, while the stratification of the water due to difference in specific gravity prevents a restoration of the supply from the saturated or supersaturated upper layers of water by hindering the mechanical mixing of the water by the tides, winds, etc.

The maximum reduction of dissolved oxygen in the Potomac Estuary and Chesapeake Bay was found in September and represents late summer conditions. At Stations 15 to 20 on this trip the dissolved oxygen was reduced to 57.5, 45.1, 21.6, 30.8, 19.7, and 45.1 percentage saturation. The actual volumes of oxygen (0° C. and 760 mm.), corresponding to the above figures for percentage saturation, are 3.2 c.c., 2.5 c.c., 1.2 c.c., 1.7 c.c., 1.1 c.c., 2.5 c.c., respectively (see Fig. 4).

It is to be expected that the maximum reduction in the dissolved oxygen content of the denser bottom layer of water would occur at this season of the year, since the supply of decomposable organic matter from plankton form, vegetation, etc., is greater during the summer months, and bacteria which assist in the breaking down of the organic matter are most active at this season, because of the higher temperature. It will be noted, from an inspection of the curves for seasonal variation in temperature (Fig. 8), that the water was about 23° C. at this time. In October the temperature had fallen to about 17° C., and in March was about 2° C., the lowest temperature noted.

Lebedinzeff[5] reported diminished dissolved oxygen content at depths of 183 to 200 metres in the Black Sea, and it is of interest to note that no life was found below 183 metres. As in the Potomac Estuary and Chesapeake Bay, vertical circulation was cut off in the Black Sea by stratification due to increase in concentration with increased depth.

It appears that thermal stratification may exist to a slight extent in the Potomac Estuary (Fig. 8). However, the variation in temperature of the surface and deep samples is generally of the order of 1° C. or less. This body of water may be regarded, therefore, as homothermous.

The chlorin and dissolved oxygen curves for May, 1912, and for April, 1913, are very similar, and their comparison is of interest, as showing the annual recurrence of seasonal conditions (Figs. 3 and 7).

SUMMARY.

It has been shown that the lower layers of certain tidal waters under investigation contain less dissolved oxygen than the upper layers. Evidence has been presented to show that this phenomenon is caused by the stratification of the water due to the specific gravity of the under-run of sea-water, which cuts off vertical circulation, and to the subsequent depletion of the oxygen in the lower layers by natural agencies. The depletion of oxygen was found to be greatest in September. The precipitation and sedimentation of matter in tidal areas by sea-water have been presented in graphic form. These data are considered to be of particular interest from the viewpoint of fish and shellfish life.

Washington, D. C., June, 1917.

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[3] Cummings, Bul. 104, Hyg. Lab., Wash., pp. 224, 229.

[4] Purdy, Hyg. Lab., Wash., Bul. 104, pp. 152, 190.

[5] Lebedinzeff, "Aus. der Fischzuchtanstalt Nikolsk," No. 9, pp. 113-136 (1904); abstract, Wis. Geol. and Nat. Hist. Sur., 1911, Bul. 22, p. 60.

Heating Houses With Gas. E. D. Milener. (*American Gas Engineering Journal,* vol. cvii, No. 18, p. 393, November 3, 1917.)—As a producer of heat units on the generous scale requisite for such service as house heating, manufactured city gas has not in the past been able to compete with coal, and the householder has had to accept the inconveniences of the latter fuel. There are, of course, other economies than those of fuel cost gained by the use of gas, and latterly, in Baltimore, the Consolidated Gas, Electric Light and Power Company has demonstrated that fuel-gas house heating is possible by the maintenance of a house-heating service supplying 500 dwellings.

An efficient furnace is a prerequisite to success with gas fuel. Even with gas at 35 cents a thousand cubic feet and coal at $8.50 a ton, the average fuel cost of heating an entire house with gas will be at least 25 per cent. more than with coal, and to keep this difference from being greater it is necessary that the best equipment only be used and proper attention given to its operation. A three-story cottage equipped with a gas-fired steam-heating system consumed, during the eight months from October to May, 465,800 cubic feet of gas. The lowest monthly consumption, during October, was 23,700 cubic feet, and the highest, during February, was 88,700 cubic feet.

STUDIES IN ACTINOCHEMISTRY.*

BY

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It is also interesting to note the observations of Cohen and Wassiljewa,[116] that equilibrium is brought about in absence of light by submitting a mixture of hydrogen and chlorine to the catalytic action of charcoal.

They found, also, that if gaseous hydrochloric acid was passed through a quartz tube which was two centimetres from the lamp (a mercury quartz lamp), and this tubing was protected from all light, the gas was decomposed. If the quartz tube was replaced by glass no decomposition of the hydrochloric acid took place.

Russ,[117] in his paper on the action of the silent electric discharge on chlorine, after a description of experiments concludes that an active form of chlorine is produced by the silent electric discharge and by ultraviolet light, and that this action of chlorine will greatly diminish when the light or discharge is taken away. He noted the dependence of the activity on moisture, and pointed out the analogy between the effects of moisture on the activation of chlorine by the silent electric discharge and those in which activation was accomplished by means of light pointed out by Mellor,[118] Gautier and Helier,[119] and Bevair.[120] He believed that the action of the discharge was photochemical, because the effect was produced in a quartz chamber much better than in glass. He found that the charged chlorine held its activity for a long time, but would lose it on being heated or passed through glass tubing. This observation, made also by Bevan,[121] is important, as the phenomenon is exhibited by gases known to be electrically charged.[122]

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* Concluded from page 636, vol. 184, November issue.

[116] *Loc. cit.*

[117] *Monatsch.*, 26, 627–646 (1905).

[118] C. B. I., 1057 (1904).

[119] *Compt. rend.*, 124, 1267 (1897).

[120] *Proc. Roy. Soc.*, 72, 5, (1903).

[121] *Loc. cit.*

[122] See J. J. Thompson, "The Conduction of Electricity Through Gases."

In his experiments, Russ used benzene as a proving substance, and found that the maximum effect of sunlight on chlorine and benzene is localized in the ultraviolet portion of the spectrum.

In this connection it may be pointed out that Warburg[123] found that there was a maximum in ozone formation by the silent electric discharge, and that the laws of Faraday did not apply to the formation of ozone. He expresses the idea that the action of the silent electric discharge must be conceived as being photo- or cathodo-chemical in character.[124]

After several attempts to chlorinate acetic acid by electrolysis under various conditions, Schluederberg[125] concludes that, "while it is possible to chlorinate acetic acid electrolytically, yet from the standpoint of efficiency the results obtained are of a very unsatisfactory nature." Schluederberg conducted his experiments on a belief "that light causes a dissociation." Bancroft[126] considers that positive and negative chlorine are produced by dissociation caused by light, and that the dissociation effects of light can be duplicated electrolytically and that light and halogen carriers act in the same manner, but it has since been found that in toluene electrolytic chlorine substituted in the ring, and ordinary chlorine in the presence of sunlight in the side chain. This would indicate that the chlorine substituted in acetic acid is the same as that substituted in the side chain in toluene. Schluederberg designates this chlorine positive, in distinction to that which enters the ring of toluene and benzene, which is called negative. The positive chlorine is considered as replacing the hydrogen of the acid, which subsequently unites with the negative chlorine and forms hydrochloric acid. By this reasoning the postulate that dissociation effects of light can be duplicated electrolytically does not hold, and it is seen that their action can be duplicated electrolytically only when halogen carriers act in a different way from light. Ferric chloride, on the other hand, can be considered as dissociating into ferrous chloride and negative chlorine. This action can be duplicated electrolytically. With phosphorus pentachloride dissociation may occur into phosphorus trichloride and positive chlorine, thus accounting for its activity.

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[123] *Ann. Phys.*, 9, 781 (1902); *Ibid.*, 13, 464 (1904).

[124] See also Regener, *Ann. Phys.*, 20, 1033–1046 (1906).

[125] *J. Phys. Chem.*, 12, 583–589 (1908).

[126] *J. Phys. Chem.*, 12, 439 (1908).

Because of the small amount of chloracetic acid obtained Schluederberg believed that what was formed was due to ordinary chlorine discharged from the electode and dissolved in the acid, and not from negative chlorine set free from the anode.

The above considerations give us reason to believe that the action of light is to ionize the chlorine. Similarly to the manner in which the ionization of other gases by light, X-rays, or silent electric discharge takes place, in which cases the gases are known to contain free ions.[127] McClung describes two interesting experiments [128] which prove conclusively that the charged gas can be carried along a tube for some distance before it loses its charge.

CHLORINATION OF BENZENE.

Another reaction which is accelerated by light energy is that between chlorine and benzene. The effect of light on this reaction was reported first by Mitscherlich,[129] who formed chlorbenzene by allowing chlorine to act on benzene in the sunlight.

Willgorode [130] reported that benzene does not react in the dark with chlorine at any temperature up to the boiling-point of the solution under atmospheric pressure. In spite of his work, it is stated in several text-books and in the literature [131] that chlorine does react on boiling benzene in the dark. This latter view was prevalent until Slator,[132] followed by Goldberg,[133] proved the reaction between chlorine and benzene to be photochemical. In his work Slator [134] pointed out that the velocity of the reaction was directly proportional to the square of the chlorine concentration—a phenomenon which is pointed out by Goldberg [135] as an exception to the usual laws governing the velocity of photochemical reaction.

It may be noted, also, that Bodenstein and Dux [136] found that the combination of hydrogen and chlorine was a reaction of the second order, the velocity being proportional to the square of the chlorine concentration.

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[127] See J. J. Thompson, *loc. cit.*, and McClung, "Conduction of Electricity Through Gases and Radio-activity."

[128] Pages 61 and 92.

[129] *Pogg. Ann. Phys. u. Chem.*, 351 (5), 370–374 (1835).

[130] *J. Prakt. Chem.*, 34, 264 (1886).

[131] Lesimple, *Lieb. Ann.*, 137, 123.

[132] *Z. Phys. Chem.*, 45, 513 (1903).

[133] *Z. wiss. Phot.*, 4, 61–107 (1906).

[134] *Loc. cit.*

[135] *Loc. cit.*

[136] *Z. physik. Chem.*, 85, 297–328 (1913).

Goldberg[137] points out the peculiar effects due to dispersion of light when the reaction between benzene and chlorine is carried out in a glass tube. He found that if concentric tubes were used, under the circumstances, the velocity of the reaction in the outer tube was less than in the inner tube, although the strength of the light is greater in the outer container than in the inner one. He calls attention to the concentration of the light following its dispersion by entrance into the outer vessel to account for these somewhat paradoxical results. The apparatus which he used for his further researches avoids the possibility of such peculiar effects by causing the light to pass through a flat piece of glass or quartz.

Goldberg found by plotting curves showing the concentration as a function of the time, velocity as a function of the time, and velocity as a function of the concentration, that the course of the reaction between benzene and chlorine could not be predicted by using the usual photochemical laws. He points out that, while with a small initial concentration the velocity diminishes with decreasing concentration, with high concentration it increases with decreasing concentration. He also found by experiment that in higher concentrations the phenomenon of self-acceleration was exhibited.

Goldberg, whose work was extensive on this phenomenon, showed that the extent of retardation in this reaction by the presence of oxygen was very marked with increasing concentration.

Luther and Goldberg[138] also found that the action of chlorine on benzene was greatly retarded in the presence of oxygen. They pointed out that this retardation probably would account for the reaction between chlorine and benzol in boiling solutions, as reported in text-books. Their experiments showed that there was little reaction in the dark even at high temperature, and they believe that the extreme sensitiveness of the reaction in the absence of oxygen makes it probable that the light of an ordinary laboratory is sufficient to bring about the reaction in a boiling solution. They believe that the formation of hexachlorbenzene in the absence of catalyzers is a purely photochemical reaction. Hexachlorbenzene cannot be formed in the dark in the presence of alkalies.

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[137] *Loc. cit.*

[138] *Z. physikal. Chem.*, 56, 43–56 (1906).

Dyson and Harden[139] pointed out that the retardation by oxygen was characteristic of all photochemical gas reactions. This observation was confirmed by Luther and Goldberg.[140]

It is of interest to note that a patent was recently granted to Sparre and Masland[141] for apparatus to be used in chlorinating saturated hydrocarbons. The material is charged with chlorine in an opaque absorption chamber, then passed through a series of glass tubes in which it is exposed to a mercury vapor light.

Attention has already been directed to the unsuccessful attempts of Schluederberg to form chlorbenzene and chlortoluene electrolytically. Van Name and Maryott[142] also report experiments which indicate that anodichlorination of benzene is absent, and that the chlorination found was due to a catalytic action of lithium chloride used, whether the chlorine is liberated by the electric current or simply introduced by bubbling it through the solution.

CHLORINATION OF TOLUENE.

Referring to another reaction, the chlorination of toluene, which is accelerated by the action of light and offers some interesting features, Bancroft,[143] cites the work of Schramm,[144] who reported that chlorine was substituted in the side chain when it acted on toluene at 0° in the sunlight, and that of Cannizzaro,[145] who reported side-chain substitution when chlorine acted on boiling toluene, and says that it is probable that the latter method of preparation is a photochemical one.

Cohen, Davison, Blochey, and Woodmansey[146] studied variations in the conditions of the chlorination process of toluene. Their experiments were divided as follows:

Series 1 and 2: Chlorination above a layer of hydrochloric acid solution (D1.16) in the dark and in diffused sunlight.

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[139] *J. Chem. Soc. Trans.*, 83, 201 (1903).

[140] *Loc. cit.* See also Bodenstein and Dux, *Loc. cit.*, and Taylor, *loc cit.*

[141] *Loc. cit.*

[142] *Am. Jour. Sci.*, 35, 153–170.

[143] *Loc. cit.*

[144] *Ber.*, 18, 606 (1885).

[145] *Compt. rend.*, 41, 517 (1855).

[146] *J. Chem. Soc. Trans.*, 87, 1034 (1905); 97 (2), 1628–1636 (1910).

Series 3 and 4: Chlorination with moist chlorine in the dark and in diffused daylight.

Series 5 and 6: Chlorination with dry chlorine in the dark and in diffused daylight.

The toluene in all cases was heated to the boiling-point.

These authors report experiments in which the chlorine was exposed to the light of an arc lamp focussed on the wash bottle of sulphuric acid before it came in contact with the toluene; others where the chlorine was exposed to diffused daylight, the sulphuric acid being replaced by water; others where the light of an incandescent electric lamp was allowed to act on the chlorine while entering the toluene.

They conclude that the proportion of side-chain substitution products obtained is not attributable to the influence of chlorine previously exposed to light.

The authors also show by experiment that the influence of light on the ratio of distribution of chlorine is very pronounced in the case when the reacting chlorine was passed through concentrated aqueous hydrochloric acid in contact with toluene. The effect of illumination was to raise the proportion entering the side-chain substitution from 16 to 60 per cent. Where moist gas was passed direct into toluene the percentage of benzyl chloride formed was raised from 60 to 90. When, however, the dry gas is passed into dry toluene in the dark the proportion of substituted products obtained is so large that any considerable influence of light is excluded. The effect of light in this case is very slight, the proportion of benzyl chloride being increased from 90 to but 94 per cent. The authors found that in the dark the distribution of chlorine is very largely dependent on the amount of water present. They further found that electrolytic chlorine in the dark gave rise to a somewhat smaller proportion of benzyl chloride than chlorine which is obtained by the action of potassium permanganate on hydrochloric acid. The fact that the conditions were not identical, due to the hydrogen liberated at one pole, was noted, a possible explanation being that the benzyl chloride which dissolved in the hydrochloric acid was reduced by the hydrogen, thus accounting for the small proportion of the benzyl chloride in the product.

If the chlorination by electrolysis is carried on in the light, the action is not sensibly different from that which occurs when ordinary chlorine is used.

The authors state that, "from a consideration of all the observations relating to the chlorination of toluene, it appears to be established that side-chain substitution is favored by light, rise of temperature, and absence of moisture."

They also conclude that the mechanism of the process of chlorination is of the same kind as that of bromination, and suggest that the more extensive observations relating to the bromination of toluene may be utilized in the elaboration of a general theory of halogenation.

There are two essentially different views in explanation of the various observations relative to the bromination of toluene under many varying conditions studied by Holleman, Polak, Van der Loan, and Envas.[147] The essential point of the one advanced by Bruner is that side-chain substitution is due to molecular bromine, whereas nuclear substitution is effected by bromine atoms or ions which result from the dissociation of the bromine molecules. The hypothesis is strengthened by the velocity measurement made by Bruner and Blusha.[148] The action of carriers is thought to be due to formation of compounds of bromine which undergo dissociation with the production of bromine atoms or ions in much greater concentration than in that which exists in a pure solution of bromine.

Bruner's theory is, in its essential characteristics, adopted by Bancroft, who gives a review of the subject of the chlorination and bromination of toluene and benzene in his third article on the "Electro-chemistry of Light."[149] He adds that the nuclear substitution takes place only when negative bromine ions are in excess of the positive ions, a condition brought about by the partial combination of the positive bromine ions with molecular bromine to form complex positive ions; for example, Br_3.

The second view, that of Holleman, is based on the supposition that substitution in the side chain is due to the molecular bromine, while that in the nucleus is brought about by hydrogen perbromide.[150] He points out that this compound is most abundant at low temperature where low concentration of bromine is employed, which is the condition under which bromine enters the nucleus. It was noted, also, that the addition of acetic acid or nitrobenzene probably acts by changing the concentration of the bromine.

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[147] Proc. K. A. Kod, *Wetensch. Amsterdam*, **8**, 512 (1905); *Rec. Tra. Chem.*, **27**, 435 (1908). See also Branerad Dlusha, *Bull. Acad. Sci. Cracow*, 693 (1907), and Jackson and Field. *Amer. Chem. Jour.*, **2**, 10 (1881).

[148] *Loc. cit.*

[149] *J. Phys. Chem.*, **12**, 417 (1908).

Cohen, Davison, Blochey, and Woodmansey[151] say that "both of these views offer a plausible explanation of certain facts, but the view that nuclear substitution is due to halogen in the form of polyhalogen compounds appears to be more acceptable." They refer to the diminution in the relative amount of nuclear substitution with rise of temperature and with diminishing concentration of the halogen as being both consistent with this theory, because they both favor dissociation of the polyhalides. They further refer to the increase in the percentage of nuclear substitution product when certain solvents are added as being in accord with the fact that these solvents facilitate the formation of polyhalogen compounds.

It is suggested as possible that the relative stability of polyhalogen compounds in nitrobenzene solution is connected with the ionizing power of this solvent. Attention is called to the slight conductivity demonstrated by Davison and Gwaler,[152] and Davison and Jackson.[153] Other solvents which favor the formation of polyhalogen compounds and increase the relative amount of nuclear product in the bromination of toluene also yield solutions which have a high electrical conductivity.

Cohen, Davison, Blockey, and Woodmansey[154] say that although there is no direct evidence to show that the nuclear substitution effect is conditioned by the ionization, yet these facts would seem to indicate that halogen in the form of polyhalogen ion is especially active in this respect.

These authors point out the following facts, which are difficult to reconcile with the ionic theory: That Bruner[155] found that solutions of bromine and iodine in moist nitrobenzene were conductors of electricity, while Brunner and Galechi[156] found that solutions of chlorine in nitro-benzene do not conduct electricity, and yet the processes of chlorination and bromination appear to be effected in a similar way when the conditions of the two processes are similarly altered.

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[150] HBr_n.

[151] *J. Chem. Soc. Trans.*, 97, 1623–1636 (1910).

[152] *J. Chem. Soc. Trans.*, 81, 525 (1902).

[153] *Ibid.*, 93, 2063 (1908).

[154] *Loc. cit.*

[155] *Bull. Acad. Sci. Cracow*, 731 (1907).

[156] *Zeit. Electrochem.*, 16, 204 (1910).

Neither theory will account for the fact that water in the toluene increases the relative proportion of the nuclear substitution products. Observations on the conductivity of toluene solutions of moist and dry chlorine show no difference that would account for the observed action on the "chlorine ionization theory," since the action of moisture opposed that of light.

In connection with the theory of carriers, that their action is due to concentration of halogen ions as a consequence of the formation of more highly ionized carrier-halogen compounds, it is stated that it is not supported by any experimental evidence, so far as these authors are aware. It is pointed out, on the other hand, that if such "carrier-halogen compounds" are themselves of the nature of perhalogen compounds, or if they are capable of combining with further quantities of halogen to form such perhalogen derivatives, the formation of nuclear substitution products in the presence of carriers is explicable in terms of the polyhalogen theory without the necessity of formulating any additional electrical hypothesis. "From a consideration of the valency relationships of the various substances which serve as carriers it seems likely that all these substances are capable of forming dissociating halogen addition compounds which belong to the polyhalogen type."

Cohen, Davison, Blockey, and Woodmansey[157] called attention to a change in color when moist chlorine acted on toluene in the presence of light. The toluene gradually assumed the yellow color of chlorine. If hydrochloric acid gas was passed in simultaneously, the yellow color disappeared, but reappeared when the hydrochloric acid was cut off. In the dark the yellow color was retained in the presence of hydrochloric acid. In some cases the color is retained after washing the product until free from hydrochloric acid and chlorine. They suggest that a small quantity of a yellow-colored substance was formed. This phenomenon was to be the subject of further research.

Haussemann and Beck[158] made the interesting observation that side-chain substitution of chlorine in nitrotoluene was greatly facilitated by the presence of sulphur. Sulphur thus appears to act differently from the usual carriers, such as ferric chloride, molybdenum chloride, antimony chloride, iodine chloride, pyridin, and aluminum-mercury couple, which bring about nuclear substitution.

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[157] *J. Chem. Soc. Trans.*, 97, 1623–1636 (1910).

[158] *Ber.*, 25, 2445 (1892).

The boiling-points of the chlorine derivatives of toluene are given by Rosenthaler.[159]

EFFECTS OF CHEMICALLY ACTING RAYS ON NITROGEN COMPOUNDS WITH SPECIAL REFERENCE TO TRINITRO-TOLUENE.

There are several references in the literature to the action of light on nitrogen compounds, its action on the nitro-explosives being particularly interesting and, in view of the existing conditions in Europe, of no small importance.

Abel[160] reported experiments on the action of light on gun-cotton conducted by him about 1867. A sample very carefully washed and dried was exposed in a closed vessel to diffused sunlight for three years. A piece of litmus paper enclosed with it turned red in three months and was bleached within twelve months. After twelve months the cotton possessed a faint but decided cyanic odor. No nitrous vapors were perceptible at any time, though the odor was apparent during the latter part of the experiment. Although the gun-cotton showed no change in explosive power, strength of fibre, or other noticeable properties, the above observations indicate decomposition. The results obtained up to that time by exposure of gun-cotton to light were reported to be as follows: Exposure to strong daylight and to sunlight, either in the open or in confined spaces, for a few days (two or three), develops in the gun-cotton a very faint aromatic odor; and if litmus paper is allowed to stand in close contact with the confined material it acquires a rose-colored tinge similar to that produced by carbonic acid, and recovers its original color after brief exposure to air. If, after exposure to light in open air for some days, the gun-cotton is placed in the dark, in containers which are not air-tight, the odor gradually becomes less distinct. If, however, the packages containing the gun-cotton are air-tight, the odor and action upon litmus do not increase during storage for several years. On exposure for protracted periods to daylight, with free excess of air, gun-cotton speedily loses all odor and power of affecting litmus. If exposure to diffused daylight in confined spaces be continued the first effects of the action of light are, of course, retained, but no evidences of increased action have been observed. The very faint acid reaction found in the early stages of decomposition was not always evident later, probably, it is thought, because the acid was neutralized by the small quantities of earthy carbonates present in the cotton. On exposure of the material in an air-tight space to the action of sunlight or strong daylight there appeared, after a time, much greater evidence of change than that already described. The acidity gradually became more decided, the odor increased, the presence of nitrous oxide was apparent, and litmus paper confined in the vessel with the cotton became bleached in three or four months.

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[159] "Der Nachweis organischer Verbindungen," 1914, p. 464.

[160] MacDonald, *Arms and Explosives,* 17, 150–152 (1909).

Reference is made to the work of DeLuca, who reported apparent change in the gun-cotton after very short periods of exposure to light (one day or several days). These results, however, are at variance with those reported by MacDonald.[161] Experiments showed that dry gun-cotton undergoes very slight decomposition when exposed to strong daylight in closed vessels, either containing air or exhausted. In about three years the explosive value was found to have diminished. This was attributed to the formation of lower cellulose products from the trinitro-cellulose. It was noted that on washing the cotton with dilute alkali the residue had useful explosive properties and exhibited no greater tendency to change than the original material.

The change in sunlight was found to be more rapid in a moist atmosphere, and it was further found that the rate of decomposition was dependent on the purity of the product.

It may be noted that when gun-cotton is heated gradually to 204° or 205° [162] it becomes dark brown, quite friable, and is deprived of its explosive properties.

According to Kassel,[163] nitro bodies are reduced to amido bodies by the action of light in the presence of alcohol. The part played by alcohol has not been established.

Berthelot and Gaudechon [164] showed that various kinds of smokeless powders were decomposed by exposure to ultraviolet rays in a manner similar to that due to the influence of natural agents—heat, humidity, and action of air. Samples of ten different varieties of powder were confined in quartz tubes over mercury in atmospheres of different gases and exposed to the rays from a mercury quartz arc. The temperature was kept below the point at which the powder under test would decompose. They all evolved carbon dioxide, carbon monoxide, nitrogen, nitrous oxide, and nitric oxide. These observers noted the absence of hydrogen and methane, which are products always found when explosion takes place. They point out that the acceleration of spontaneous decomposition of powder when subjected to the action of ultraviolet rays furnishes the elements of a new and precise method of investigation. Such a method would serve as an admirable substitute for the widely used heat tests for the control and complete examination of the stability of powder.

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[161] *Loc. cit.*

[162] MacDonald, *loc. cit.*

[163] *J. Suisse de Chimie. Pharm.*, 47, 722–724 (1909).

[164] *Compt. rend.*, 153, 1220–1223 (1911).

These authors [165] exposed different grades of powders in atmospheres of different gases to ultraviolet light from a mercury quartz lamp. They found that oxygen was absorbed and converted into carbon dioxide. Hydrogen was converted into CH_2 (?) and water. Carbon dioxide was absorbed at 25° to 40°, but at 75° more carbon dioxide was evolved from the powder. They pointed out that the decomposition of these powders by light yielded the same products as slow decomposition due to heat, moisture, etc. The presence of atmospheric nitrogen did not prevent the evolution of nitrogen from the powders, but in the presence of carbon dioxide there was no carbon dioxide evolved. Nitro-cellulose powders suffered no change in appearance, but change in color and exudation of nitroglycerin resulted with powders containing nitroglycerin. These authors also found that, while picric acid was slightly affected by the light, ammonium picrate was not. They called attention to the possible effect on the results of those stability tests in which the explosive is heated in carbon dioxide, and recommend nitrogen in its place. One such test is the "Will Test," which is extensively used in Germany.

Wöhler [166] showed that on exposure to sunlight or to ultraviolet light the nitrides were very quickly decomposed into the metal and nitrogen. The metal he was able to detect microscopically, and the presence of nitrogen by means of a manometer.[167] While these substances are the same as are produced by explosion, Wöhler claimed that the decay caused by light took place only at the surface, the under layers being protected by the opaque layer thus formed, and that, in consequence, the explosive properties of the substance were practically unimpaired for commercial purposes.

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[165] *Compt. rend.*, 154, 201–203, 514–517 (1912).

[166] *Z. org. Chem.*, 24, 2095 (1911); also see Wöhler and Krupko, *Ber.*, 46, 2045–2057 (1913).

The color that is produced by the action of light on the nitrides Wöhler attributed to the liberation of the free metal in colloidal form. Incidentally, he draws a comparison between this conduct of the nitrides and the similar conduct of the silver halides, and attributes the color produced in silver chloride by the action of light to the liberation of metallic silver in colloidal form, rather than to the production of subhalides.

Neitzel[168] refers to the work of Wöhler, stating that it is still conceivable that there is a light-sensitiveness in the under layers of nitride. He further points out that the dangerous auto-decomposition of large crystals which can take place even under water may be attributed less to the forces postulated by Wöhler " in his crystal tension hypothesis " than to the influence of light. He also calls attention to the necessity for confirmation of Wöhler's observation that the detonating power is not changed by the influence of light. Neitzel refers to the susceptibility of the nitrides to action of light as a possible disadvantage of their use in detonators.

Another explosive which has been the subject of experiment is synthetic trinitrotoluene. According to Molinari and Quartier,[169] this substance remains completely unaltered in dry or damp air in the dark. When exposed to bright daylight, however, it becomes brown slowly on the surface. This brown product was investigated by Doctor Milani, of the Societa Italiana Prodotti Explodenti. The original substance was solid at 80.4° and left 0.03 per cent. residue in acetone solution. By longer illumination, with frequent shaking, the solidifying point sank first to 80°, then gradually to 79.6°. The product left from 0.05

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[167] *Z. Aug. Chem.* (1911–1912).

[168] *Z. ges. Schiess-Sprengstoffw.*, 8, 211 (1913).

[169] *Ibid.*, 8, 405–407 (1913).

per cent. to 0.10 per cent. insoluble residue in acetone solution. Molinari and Giua showed that the melting-point of trinitrotoluene was lowered to 74° by exposure to daylight for three months in an open flask, and that if the flask was evacuated the browning was decidedly less and the melting-point was lowered only 0.6°.

In view of the similarity in action between heat and light, referred to above, in connection with the action of light in the formation of chlorine compounds, it is interesting to note the observations of Verola.[170] This investigator found that there was a decomposition of trinitrotoluene at temperatures much below the point at which it would deflagrate in air. He also noted that a previous heating of trinitrotoluene lowered its melting-point. On heating a sample that had an original melting-point of 80.75° for five hours at 180° the melting-point was reduced to 78°; two and one-half hours at 217.5° gave a product having a melting-point of 59°. Continued heating at 130° for one hundred hours had no effect, while 80 hours' heating of the same sample at 150° reduced the melting-point to 80.25°, and 177 hours' heating at 150° gave a further reduction to 79.9°. He says that it is evident that the explosive is very stable at 130°, decomposition beginning at about 150° and increasing rapidly as the temperature rises. He considers trinitrotoluene to be perfectly stable at ordinary temperatures.

Those who are interested in the true melting-point of trinitrotoluene are referred to the work of Comey,[171] who found it to be between 80.5° and 80.6°, and to the later work of Rintoul,[172] who gives it as lying between 80.8° and 80.85°.

Particular attention in this work has been paid to the variation in melting-point of trinitrotoluene because of its importance in grading the product with respect to its purity.

It was suggested that additional information relative to the effect of light on trinitrotoluene would be of value. Before reporting experiments on this research, however, it would seem to be of advantage to call attention to the effect of light on other nitrogen compounds.

The fact that sunlight will cause decomposition of nitric acid has been known for a long time. The first report of systematic study of the problem did not, however, appear until 1898. In that year Berthelot[173] showed that the decomposition products of nitric acid produced under the influence of light are the same as those obtained when the anhydrous acid is heated in tubes to 100° in the dark for some hours, namely, oxygen, nitrogen peroxide, and water. This reaction, which may be represented as follows:

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[170] *Ibid.*, 7, 97.

[171] *J. Ind. Eng. Chem.*, 2, 103 (1910).

[172] *J. Soc. Chem. Ind.*, 34, 60–61 (1915).

$$4HNO_3 = 2H_2O + O_2 + 2\ N_2O_4$$

was found by him to be non-reversible. A little earlier in the same year Veley and Manley[174] pointed out that the light appeared to act only on the vapor and not on the liquid. This interesting observation was confirmed later by Reynolds and Taylor.[175] Reynolds and Taylor,[176] contrary to the observation of Berthelot,[177] found the reaction to be reversible, the products of decomposition of nitric acid by light recombining in the dark. This was in accordance with the results obtained in the study of other reactions in which nitric acid took part. They illustrated the rate of decomposition and recombination by a series of curves. They further proved that pure anhydrous nitric acid decomposes very slowly in the dark, giving the same products of decomposition as are found in the light.

That nitrates also are decomposed by light was found by Thiele,[178] who obtained 24 milligrammes of N_2O_3 on exposure of 100 cubic centimetres of a one-tenth normal solution of potassium nitrate in a quartz flask to the rays from a mercury quartz lamp.

Later, Berthelot and Gaudechon[179] found that, on exposure to ultraviolet rays from a mercury quartz light, solutions of ammonia placed three to six centimetres from the lamp were oxidized in the presence of pure oxygen or air to nitrites. They state that nitrates were in no case formed. Ammonium salts were also oxidized to nitrites, the action being slower in the case of sulphates and chlorides than in the case of carbonates.

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[173] *Compt. rend.*, **127**, 143 (1898).

[174] *Phil. Trans.*, **191**, 365 (1898).

[175] *J. Chem. Soc. Trans.*, **101**, 131–140 (1912); *Proc. Chem. Soc.*, **27**, 306 (1911).

[176] *Loc. cit.*

[177] *Loc. cit.*

[178] *Ber.*, **40**, 4910.

[179] *Compt. rend.*, **152**, 522–542 (1911).

It is interesting to note in this connection that the nitrates found in meteoric waters are attributed to electric discharges taking place in the air.[180]

It is also interesting to note in this connection that Thompson[181] found ammonia was strongly ionized by ultraviolet light. It may be added that Thompson observed that the ultraviolet rays are absorbed to such an extent by passage through three millimetres of air at atmospheric pressure that they lose their ionizing energy almost entirely. Berthelot and Gaudechon[182] also report the formation of formamide from carbon monoxide, and ammonia gas.

Baker[183] found that B. p-nitrophenol, a yellow compound, slowly turned red on exposure to sunlight.

Kailan[184] found that the oxidation of o–, m–, and p–nitrobenzaldehyde and benzaldehyde was accelerated by ultraviolet light.

Benrath[185] found that on dissolving various aliphatic bodies in dilute nitric acid, containing a little ferric nitrate, and exposing to sunlight, nitrous oxide, a little carbon dioxide, formaldehyde, and large quantities of hydrocyanic acid were formed.

Bakunin[186] reported that the precipitate formed by exposing to light ethereal solutions of the phenylnitro-indones had explosive properties.

Light also has an effect on certain of the alkaloids and similar nitrogen-containing substances. This branch of the subject will be treated under the heading "The Effect of Light on Nicotine."

In considering the action of light on the nitroderivatives of benzene and its homologues it is well to note the observation of Suida,[187] who found that benzene was scarcely affected by the action of light, but that the susceptibility rapidly increased with the number of methyl groups present.

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[180] Müntz and Laine, *Compt. rend.*, 152, 167 (1911).

[181] *Proc. Camb. Phil. Soc.*, 14, 417.

[182] *Compt. rend.*, 150, 1690–1693 (1910).

[183] *Proc. Chem. Soc.*, 27, 158.

[184] *Monatsh.*, 33, 1305–1327.

[185] *J. prakt. Chem.*, 84, 324–328.

[186] *Rend. Accad. Sci. fis. mot Napoli*, 17, 375–378.

[187] *Monatsh.*, 33, 1255–1258.

Ciamician and Silber[188] confirmed the work of Suida, that benzene is not affected by oxygen and water, in the presence of light. Berthelot and Gaudechon[189] state that ultraviolet light has no effect on benzene. They further point out that in other cyclic bodies (pyrrole, furfurol, pyridine, and a few alkaloids) their behavior is in accordance with the well-known stability of the aromatic nucleus toward heat, light, and chemical reagents.

In 1906 Regener[190] showed that ammonia, nitrous oxide, and nitric oxide were decomposed by ultraviolet rays of short wavelength. In his paper he refers to the work of Berthelot,[191] who found that nitric oxide was reduced to oxygen and nitrous oxide, under the influence of the silent electric discharge. Here, again, we have evidence of the similarity of chemical action produced by light and by the silent electric discharge referred to above in the discussion of the action of light on chlorine. Further consideration of these phenomena may add weight to the hypothesis of Warburg,[192] that the action of the silent electric discharge was dependent on the ultraviolet rays present in the discharge.

Berthelot and Gaudechon[193] found that ammonia could be decomposed by ultraviolet light, but that it could not be similarly synthesized from the elements, hydrogen and nitrogen. Coehn and Prigent[194] found that ammonia was completely decomposed by ultraviolet light. Davies[195] found that the reaction between nitrogen and hydrogen under the influence of the silent electric discharge was reversible. Regener[196] showed that ammonia was decomposed by the silent electric discharge and also by the ultraviolet light.

The reversibility of the reaction between nitrogen and hydrogen was also pointed out by Smiths and Aten,[197] who reported the synthesis of ammonia from its elements under the influence of the rays from a quartz mercury light. Coehn[198] and Coehn and

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[188] *Ber.*, 46, 417–422.

[189] *Compt. rend.* 152, 262, 376–378 (1911).

[190] *Ann. Phys.*, 20, 1033–1046 (1906).

[191] *Compt. rend.*, 82, 1360 (1876).

[192] *Loc. cit.*

[193] *Compt. rend.*, 156, 1243 (1913).

[194] *Z. Electrochemie*, 20, 275–278 (1914).

[195] *Z. physik. Chemie*, 64. 657 (1908).

[196] *Berl. Akad. Ber.*, 1228 (1904).

[197] *Loc. cit.*

[198] *Jahrb. Radioakt. Elektronik.*, 7. 577 (1911).

Prigent[199] are inclined to doubt the validity of the results obtained by Smiths and Aten, pointing out that the waves of short wave-length, which would be effective in this reaction, are absorbed by quartz. They also point out that Warburg[200] showed that the percentage of ultraviolet rays absorbed by the mixed gases, nitrogen and hydrogen, was about the same as by pure ammonia. In this connection it is interesting to note the observation of Davies,[201] that the decomposition of ammonia, under the influence of the silent electric discharge, is independent of the discharge.

Berthelot and Gaudechon[202] report that ultraviolet rays produce no appreciable effect on air or mixtures of oxygen and nitrogen, but that nitrous oxide alone, or mixed with oxygen and nitric oxide, is decomposed with the formation of free nitrogen and nitrous and nitric acids.

Other compounds which contain nitrogen that are influenced by ultraviolet light were reported by the same observers. They[203] found that cyanogen in the presence of oxygen was practically completely oxidized to carbon dioxide and nitrogen. Cyanogen in the absence of oxygen was found by them[204] to form paracyanogen. They also found that a mixture of ammonia and oxygen yields nitrogen and water, and that ammonium nitrate was reduced to nitrogen.

Ciamician[205] reported the synthesis of complex mixtures when hydrochloric acid acted on acetone in the presence of light.

Berthelot and Gaudechon[206] also found that urea decomposed under the influence of ultraviolet light, evolving seven volumes of carbon dioxide, 65 of hydrogen, and 28 of methane; an aqueous solution of urea gave 84 volumes of hydrogen and 16 of methane. The residual solution was found to possess reducing properties, and to contain ammonia and ammonium carbonate. By treating aqueous solutions of ammonia with air or oxygen in the presence of ultraviolet light Berthelot and Gaudechon[207] obtained nitrous acid. Ammonium salts gave nitrites. They state that nitrogenation of various substances has been accomplished. They point out that the transformation of organic nitrogen to ammoniacal nitrogen is the first stage of nitrogenation of urea by ultraviolet rays, as is the case when nitrogenation is caused by the enzymes. They further found that nitrates could be reduced to nitrites. They point out the analogy between the reduction of ammonium nitrate to nitrogen under the influence of ultraviolet light, referred to above, and the reduction produced by heat. They refer to the observation of Lombard,[208] that potassium nitrate was reduced to potassium nitrite during sterilization of water by ultraviolet rays.

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[199] *Loc. cit.*

[200] *Berl. Akad. Ber.*, 746 (1911); 216 (1912).

[201] *Loc. cit.*

[202] *Compt. rend.*, 150, 1517–1520 (1910).

[203] *Compt. rend.*, 150, 1327–1329 (1910).

[204] *Compt. rend.*, 151, 1169–1172 (1910).

[205] See Kassel, *loc. cit.*

[206] *Compt. rend.*, 151, 478–481 (1910).

Ciamician,[209] in an address before the Société de Chimie de France, reported an unsuccessful attempt to synthesize acid amides from hydrocyanic acid by the action of light. Although the attempt failed, he states that the investigation is to be continued.

EFFECTS OF LIGHT ON NICOTINE SOLUTION.

It has been known for some time that solutions of nicotine change in strength with age when stored under different varying conditions. Of the several factors which might have an effect on these changes, that of the action of light on alkaloids has been the subject of very little study. Inghilleri[210] reports the synthesis of alkaloidal bases by the action of sunlight on a mixture of formaldehyde, concentrated aqueous ammonia, and methyl alcohol, which was confined in a sealed tube and left exposed to sunlight for seven months. Several products having basic properties and giving characteristic alkaloidal reactions were isolated. One of these, a crystalline substance, was identified as having the formula $C_6H_8N_2O$. The author gives distinguishing properties for this compound.

Sernogiotto and Hoschek,[211] in a paper entitled "Supposed Chemical Changes in Light," repeated the work of Inghilleri, but did not obtain similar results. They found that when formaldehyde and water are exposed to light practically no methyl alcohol is formed. When formaldehyde and methyl alcohol are exposed methylal is produced, but no methyl formate, and that a mixture of formaldehyde, methyl alcohol, and ammonia yields hexamethylenetetramine, which they think probably is Inghilleri's new alkaloid.

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[207] *Compt. rend.*, **152**, 522–524 (1911).

[208] *Bull. Soc. Chem.*, No. 6, vii, viii (1910).

[209] *Bull. Soc. Chem.* (4), 3–4, i–xxvii, August 5.

[210] *Z. phys. Chem.*, **80**, 64–72 (1912).

[211] *Ibid.*, **90**, 437–440 (1914).

In the same year Paterno and Maselli[212] reported the photosynthesis of a new alkaloid from acetophenone and ammonia. The reagents were put in a closed tube and exposed to light for several months. A crystalline compound which was formed was found to have the composition indicated by the formula $C_{18}H_{18}N_2$. The authors describe the properties of this product in detail. Other than these researches, little can be found, excepting that which relates to the absorption effects of light produced by certain alkaloids in solution.

Paterno,[213] in his conclusion to a series of papers on the syntheses in organic chemistry by means of light, states that the formation of organic nitrogen compounds in indefinite amounts by the reduction of nitrates in the light in the presence of organic substances may be a fruitful field for research; he refers to the synthesis of photo-acetophenine and its analogues, and suggests that the possibility of introducing into vegetable alkaloids of great physiological activity complex lateral chains is capable of having great pharmacological importance.

Just recently, Ciamicion and Silber,[214] who have done considerable work on the chemical action of light and different types of substances and different types of reactions, reported the auto-oxidation of nicotine and piperidin under the influence of light. Their experiments on nicotine were carried out as follows:

Twelve grammes of nicotine in 100 c.c. of water was placed in each of three five-litre flasks with oxygen and left in the light from May to November. The solution became a deep yellow, its reaction faintly acid, and the oxygen was almost completely used up. After diluting the contents of the flasks, an excess of barium carbonate was added and the product distilled with steam. Both the distillate and residue were examined. In the distillate were found unchanged nicotine, a small quantity of ammonia, and methyl amine. From the residue there was isolated a large quantity of a product having the same composition as the oxynicotine of Pinner and Wolffernstein,[215] and Beilstein,[216] but a different melting-point for its picric acid salt and nicotinic acid. They say, in conclusion, that the auto-oxidation of nicotine under the influence of light furnishes, besides a tar-like product as a principal product, oxy-nicotine, which by further oxidation yields nicotinic acid and methyl amine. The reactions involved can be represented thus:

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[212] *Gazz. Chim. Ital.*, 42, 65–75 (1912).

[213] *Gazz. Chim. Ital.*, 44, 463–475 (1914).

[214] *Ber.*, 48, 181–187 (1915).

$$\underset{\text{Nicotine}}{C_{10}H_{14}N_2} \rightarrow \underset{\text{Oxy-nicotine}}{C_{10}H_{14}ON_2} \rightarrow \underset{\text{Nicotinic acid}}{(C_5H_4N)COOH} + \underset{\text{Methyl amine}}{HN_2.CH_3}$$

Dobbie and Fox[217] made a study of the relation between the absorption spectra and constitution of piperine, nicotine, cocaine, atropine, hyoscyamine, and hyoscine, and confirmed a previous conclusion,[218] that the absorption spectra of the alkaloids containing reduced and unreduced nuclei are the same as those of unreduced nuclei.

Michand[219] investigated various inorganic and organic substances with the object of noting their behavior toward ultraviolet light, and found that certain of the alkaloids do not reflect ultraviolet rays. He suggests a possible relation between this property and physical and chemical properties and possible application to analytical chemistry.

Gompel, Marcel, and Henri[220] report a quantitative study of the absorption of ultraviolet rays by alkaloids, and have applied a method for quantitative determination of alkaloids in body fluids and tissues by means of the ultraviolet absorption spectra to alkaloids of the piperidine and pynolidine group.

These absorption effects are referred to because of their connection with the principle that when light is absorbed it tends to produce a chemical change.

Berthelot and Gaudechon[221] report experiments on the

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[215] *Ber.*, **24**, 64 (1891); **25**, 1428 (1892); **28**, 460 (1895): **34**, 2412 (1901).

[216] IV, 858.

[217] *Prac. Chem. Soc.*, **29**, 180; *J. Chem. Soc.*, **103**, 1193–6.

[218] Cf. Dobbie and Lauder, *C. A.*, **5**, 3563 (1911), and Dobbie and Lauder, *C. A.*, **6**, **1284** (1912).

[219] *Arch. Sci. Phys. Nat.*, **33**, 498; *Sci. Am. Sup.*, **75**, 5 (1913).

[220] *Compt. Rendu. Soc. Biol.*, **74**, 1066–1068; *Compt. Rendu.*, **116**, 1541–1544.

[221] *Compt. rend.*, **152**, 376–378 (1911).

"Comparative Action of Ultraviolet Rays on Organic Compounds of the Straight Chain and Cyclic Structure." Among the substances studied by them were pyridine and nicotine. They state that the untraviolet rays do not produce any gases with any of the bodies studied; that there was no change in color, and no visible alteration. They say that the results are different with addition compounds in which the double bonds of the nucleus have disappeared. They call attention to the fact that certain bodies such as hexahydrobenzene offer intermediate properties between aliphatic hydrocarbons and aromatic hydrocarbons. They observed that piperidine (hexahydropyridine) is decomposed by ultraviolet rays with formation of pure hydrogen. The pyridine nucleus has alternate single and double bonds which form a stable compound, while the piperidine nucleus has single bonds, forming a compound unstable toward the action of light. The authors, however, do not give the source of the light used, the distance from this source, or the length of time of exposure to the light.

HYDROGENATION OF OLEIC ACID BY LIGHT AND ELECTRIC DISCHARGE.

One of the interesting problems of chemistry has been to change the unsaturated hydrocarbons into saturated compounds by direct addition of hydrogen. A special case of such a transformation has been of particular interest because of the great commercial value of some of the products formed by hydrogenation of fatty oils. As an illustration of a decided change in the physical properties of an oil may be cited the change produced in cotton-seed oil by hydrogenation, the untreated oil being liquid at ordinary temperatures, while the treated oil is a solid at ordinary temperatures. An example of a pure chemical substance which undergoes a similar change in physical properties is oleic acid, which by hydrogenation is converted into stearic acid.

There are many successful methods for hydrogenation of the unsaturated acids, most of them requiring the use of metal catalyzers. Several methods have been proposed which involve electrolytic processes, and the use of light has been proposed in still other methods. Particular attention is called to the references hereafter mentioned which describe methods employing electricity and light.

The possibility of the use of electricity to bring about the combination of hydrogen with oleic acid was suggested by Weinech.[222]

Later, Kuess[223] attempted to apply the electric current in conjunction with steam distillation of fatty acids. Magnier, Bragnier, and Tissier,[224] attempted the hydrogenation of oils and fatty acids by nascent hydrogen produced by electrolysis.

Later, Hemptinne[225] reported satisfactory results by making use of a method in which the fatty acid was brought in contact with hydrogen in the presence of a silent electric discharge.

Hemptinne performed experiments using several types of apparatus. The first experiments were done with an apparatus resembling an ozonizer, the current being supplied by a Ruhmkorff coil. Later, experiments were performed using a modified form of apparatus and a Tesla coil.

An attempt was made by Hemptinne[226] to discover a quantitative relation between the quantity of substance transformed and the intensity of the current. It was found, however, that there is not always a proportionality between the quantity of substance transformed and the intensity of the current. For a given intensity of current the quantity transformed reached a maximum, which varied with the pressure for a definite size discharge space.

It was pointed out that it was necessary for the current to act simultaneously on both liquid and gas to obtain satisfactory results. He concludes, from a research made on the influence of polarity, " that the action is independent of the electric particles of one or the other signs."

Hemptinne lays great emphasis on the observation that there is no direct proportionality between the intensity of the current and quantity of material transformed. " But," he says, " if one admits that the passage of the electricity does not interfere with the electric particles, it is necessary to conclude that these play only an indirect rôle in the phenomena." " This," he adds, " is not the same as in electrolysis of liquids, where there is always parallelism between chemical activity and the number of ions." Because of the complicated nature of the action produced by prolonged use of the current he believes it is impossible to draw positive conclusions.

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[222] *Osterr Privil.*, **10**, 400, July 19 (1886); fr. Ellis, " Hydrogenation of Oils," 13.

[223] *Chem. Ztg.*, **618** (1896).

[224] British Patent 3363, 1900; German Patent 126,446 October 3, 1899, and German Patent 132,223; Ellis, *loc. cit.*

[225] *Bull. Soc. Chem. belg.*, **26**, 55–63 (1912); U. S. Patent 797,112, August 15, 1905, fr. Ellis, *loc. cit.*

[226] *Loc. cit.*

Hemptinne found that the yield was dependent upon a great number of conditions, and called attention to the differences in yield which were functions of the period of vibration of the current, current density, pressure of the gas, temperature of the liquid, and space through which the discharge passed.

In view of the observation of Russ,[227] which indicates that the action of the silent discharge in accelerating the reactions between chlorine and benzene is due to light rays, it is suggested that the effects brought about with the apparatus used by Hemptinne would be greatly intensified if an ozonizer having one quartz plate instead of glass were used.

Marie [228] was able to reduce aconitic acid to tricarballylic acid, and cinnonic acid to phenylpropionic acid by electrolysis of an acid solution of a sodium salt of the acid to be reduced. There was no difference in the yield when different metals were used as cathode.

Petersen [229] reported a method for obtaining stearic acid from oleic acid by means of an electric current between nickel electrodes placed in an alcoholic solution of oleic acid to which a mineral acid had been added; as, for example, sulphuric or hydrochloric acid. Petersen tried also other cathode materials than nickel, and found that the results were no more satisfactory with platinum, lead, zinc, or mercury as cathodes. Less satisfactory results were obtained by an attempt to obtain an increased yield by conducting the electrolysis in alkaline aqueous and alkaline alcoholic solutions.

A year later Böhringer and Sohne,[230] working on the same principle as did Petersen, reported better results with other electrodes, especially cathodes of platinized platinum and also palladium electrodes covered with palladium black.

Utesher [231] uses both a silent discharge and a catalytic agent in the saturation of an acid with hydrogen. Later patents on a process involving treatment of fatty acids and their glycerides with hydrogen in the presence of catalyzers and chemically acting rays have been taken out in Austria.[232]

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[227] *Monatsch.*, 26, 627–646 (1905).

[228] *Compt. rend.*, 136, 1331–1332 (1903).

[229] *Z. Elektrochem.*, 549–553 (1905).

[230] German Patents 187,788, 189,332 (1906). Ellis, *loc. cit.*, p. 5.

[231] British Patent 20,061, fr. Ellis, *loc. cit.*, p. 33; German Patents referred to in *Seinfen Ztg.*, 40, 851 (1913).

Utesher [233] also outlines a process for the hydrogenation of the unsaturated fatty acids or their glycerides, using the silent electric discharge. He states that care was taken that the "induction spark" was prevented from coming into contact with the fatty substances, and that only the chemically acting rays of the discharge were utilized; for example, those from a mercury quartz lamp. Utesher also obtained positive results by letting the silent electric discharge act on a catalyzer, thus not only assisting it in maintaining its activity, but in actually increasing its effect. The apparent activation of the catalyzer may be explained by the ionization of the hydrogen brought about by photo-electric forces.

Utesher,[234] in a German patent, claims a process for transforming the saturated fatty acids and their glycerides into saturated compounds by means of hydrogen. The fatty substances in the presence of hydrogen are subjected to the simultaneous action of a metallic catalyzer and the silent electric discharge.

Gruer,[235] subjected fats and oils to the action of an electric current of high potential,[236] and claims a greater effect for both current and catalytic substance when combined than for either when used separately. In this connection it is of interest to point out the observation of Farmer and Parker [237] that ultraviolet light exerts a retarding effect on the catalytic action of colloidal platinum used for breaking down hydrogen peroxide.

Ellis,[238] in commenting on the work of Farmer and Parker, says that it would appear that exposure to ultraviolet light may be expected to modify the rate of reaction in the hardening of oils. In a footnote he states that preliminary experiments point to a reduction in the iodine number of cotton-seed oil when exposed to ultraviolet light in an atmosphere of hydrogen.

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[232] *Seifen Ztg.*, 1298 (1913).

[233] "Cem. Rev. Fett.," Hertz, *Ind.*, 305 (1913).

[234] German Patent 266,662, February 18, 1912.

[235] French Patent 453,664, January 27, 1913.

[236] 50,000 to 100,000 volts.

[237] *J. Am. Chem. Soc.*, 1524 (1913).

[238] "Hydrogenation of Oils," p. 34.

Walter[239] proposed a method for the hydrogenation of oils in thin films in which he used a catalyzer, and mentioned that the operation might be carried out with the aid of chemically acting light. A patent by Walter[240] has to do with the acceleration of chemical reaction between liquids and gases by means of a contact substance or chemically acting rays.

Fuchs[241] calls attention to several theoretical considerations which if followed would facilitate the reduction of fatty bodies by hydrogen. He found that the velocity of the reaction was increased if the oil to be treated be held at a moderate temperature (0° to 150°), while the hydrogen employed is raised to higher temperature (200° to 250°). Maintaining the oil at low temperature is said to increase the quality of the final product, while the preheating of the hydrogen appears to increase the activity of the gas. Referring to the analogy between the action of heat and ultraviolet light, the above observation might furnish grounds for concluding that light might supply the necessary energy for accelerating this reaction.

Fuchs believes that it is necessary for the hydrogen to be in the atomic state before it is capable of acting on the fatty mineral. This production of the atomic state, he states, can be brought about through the application of chemically active rays. It also appears that the hydrogen molecule is dissociated when molecular hydrogen is pased over a catalyzing agent, such as platinum black or freshly prepared nickel powder, and then is allowed to diffuse under high pressure over heated plates of metal. This phenomenon would be evidence for believing that the hydrogen was ionized. Reference is made to experimental work, but no details are given in which light is employed as an aid to the reaction.

EXPERIMENTAL.

Chlorination of Acetic Acid.

An attempt was made to prepare a substitution product of acetic acid by the action of chlorine on acetic acid in the presence of artificial light.

The essentials of the method used were as follows: Chlorine, generated by the action of hydrochloric acid on potassium permanganate, was first washed with water, then with concentrated sulphuric acid, and finally passed into a quartz flask containing glacial acetic acid. The flask, fitted with a reflux condenser, was heated on a steam bath and exposed to the source of illumination. It was found that under the influence of the rays from an iron arc, placed three centimetres from the flask, monochloracetic acid was obtained, the yield being greater if red phosphorus was used as a catalyzer. Under the influence of the rays from a projection lantern about five centimetres from a glass flask, the other conditions being the same as in the previous conditions, no substitution product of acetic acid was obtained. While the negative results may have been due to the lack of intensity of the light of active wave-length and its rather limited space of action, it is probable, also, that the most active rays were excluded by the glass.

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[239] *Seifen Ztg.*, 442 (1913).

[240] German Patent 257,825, July 27, 1914; fr. Ellis, "Hydrogenation of Oils, p. 36.

[241] *Seifen Ztg.*, 40, 982–983 (1903); Belgian Patent 256,574 V–15V (1913).

An attempt was made to prepare chloracetic acid by the action of chlorine activated by the use of ultraviolet rays. Chlorine, generated by the action of hydrochloric acid on manganese dioxide, was first purified with water and sulphuric acid, and then led through a quartz tube, 6 millimetres in diameter and about 75 centimetres long, into the flask containing glacial acetic acid. With the fact in mind that when any substance phosphoresces by the action of light it gives off charged particles of electricity capable of causing ionization in certain gases; the tube was placed on a bed of powdered fluorite. A quartz mercury lamp which operated in a 110-volt circuit was used as a source of illumination. The potential across the arc was about 80 volts. The lamp was placed above and close to the tube, so as to get a maximum effect of the waves of shortest length produced. The results of this investigation were negative.

Chlorination of Benzene and Toluene.

Experiments were performed to obtain chlorine substitution products of benzene and toluene, which paralleled in all cases those above mentioned, except with regard to temperature conditions.

At room temperatures and without catalyzers these substitution products were not obtained under the influence of the light from a projection lantern, but they could be obtained at room temperatures under the influence of the rays from an iron arc.

While an effort to obtain a substitution product of benzene using chlorine, activated by the rays emanating from a quartz mercury arc, gave (as with acetic acid) negative results, chlorination products of toluene could be obtained under similar conditions.

An endeavor was then made to chlorinate benzene and toluene at room temperatures by activating the chlorine through the agency of an electric discharge. The chlorine, generated by the action of hydrochloric acid on potassium permanganate, was purified and then led through a Siemens ozonizer into a wash-bottle which contained the benzene or toluene and was protected from the light by black paper and cardboard. The ozonizer was connected with the secondary terminals of a small induction coil capable of producing a three-centimetre spark. The results were negative.

Trinitrotoluene.

As stated above, the melting-point is of great importance in grading trinitrotoluene. The following experiments were conducted to see what effect light would have in lowering the melting-point of trinitrotoluene. The product used was one obtained from Professor Munroe, of the George Washington University.

Each sample on which observations were to be made was placed in a small "melting-point tube" made as described in Gattermann's "Practical Methods of Organic Chemistry."[242] A small cotton plug was placed in the top of the tube, and the opening was then closed with soft wax.

It was found during this work that trinitrotoluene was decomposed by sunlight, as evidenced by a darkening of the cotton plugs in the tubes, as well as by a decided lowering of the melting-point, which changed from 80.47° to 80.18° after exposure for one day, to 79.27° after exposure for one week, to 78.37° after exposure for two weeks and 77.50° after four weeks. After two hours' exposure a slight color change, but no apparent change in melting-point, was developed. It was noted, also, that the melting-point was less sharp after exposure to light, and that where decided coloring was evidenced examination under a microscope showed two sets of crystals, one set being a much darker brown, although the form was the same.

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[242] Page 66 (1909).

A sample of trinitrotoluene was placed in a capillary tube made of quartz. This tube was kept in the path of the rays emanating from an iron arc (see above), which was placed 1.5 centimetres from the tube. After six hours' exposure the product was examined. It had turned a dark brown and had a melting-point of 79.06°.

Samples of trinitrotoluene, melting-point 80.47°, were placed, one in a capillary tube made of quartz, and another in a capillary tube made of glass. These tubes, together, were placed on a table 7 centimetres from a mercury quartz lamp. The heating effect of the lamp on the tubes was greatly reduced by employing a mechanical blower, so arranged as to drive a constant stream of air over the tubes. The temperature indicated by the thermometer was 30° at the beginning and 40° at the end of a three-hour period. After an exposure of the above duration the samples were examined. There appeared to be no darkening of the crystals in either tube. The melting-point of both specimens was found to be the same, namely, 80.21°.

In view of the previous experiment, this identity in the change of melting-point in samples contained in glass and quartz, and exposed to the rays from a mercury quartz light, seemed surprising. This experiment, however, indicates that artificial light materially affects trinitrotoluene, and that the long ultra-violet rays (*i.e.*, those which can pass through 7 centimetres of air) have little, if any, greater effect than the "visible" rays from a mercury quartz arc.

An experiment was performed to study the effect of sunlight on trinitrotoluene in the absence of air. It was thought that, inasmuch as the evolution of gases indicates, in general, chemical change, the use of an apparatus which would detect any such evolution would prove of value in the demonstration of the decomposition of the substance under examination. Some of the product was therefore placed in a "fermentation tube" of the type commonly used by bacteriologists in detecting gas formation by bacteria. The air in the tube was displaced by mercury. The crystals did not rise to the top of the tube, as was expected, but clung to the sides. The tubes were placed on the window-sill of a south window and allowed to remain three weeks. Observations were made every day, but there was no immediate change. As time passed, however, the product grew darker gradually, though much more slowly than in those cases when air was present. There also appeared to be a slight evolution of gas, which remained in contact with the crystals. The amount was too small, however, to admit of identification. It was also noted that the part of the sample which was on the side of the tube not exposed to the direct sunlight showed very little change.

The above experiments not only confirm the observations of Molinari and Quartieri,[243] but establish the fact that the ultra-violet rays are more active in producing decomposition of trinitrotoluene than rays of longer wave-length. They further indicate that the change in trinitrotoluene when exposed to light is due to oxidation.

Nicotine and Pyridine.

A study of the effects of light on nicotine and pyridine solutions, both dilute and concentrated, shows:

That there is a change in nicotine content when nicotine solutions are exposed to sunlight.

That this change is more marked in the presence of air—a fact which indicates an oxidation process.

That ultraviolet light produces a change in the nicotine in nicotine solutions.

That sunlight produces a change in pyridine in pyridine solutions.

The experiments with nicotine solutions were made on 0.1 per cent. solutions and 40 per cent. solutions which were exposed to sunlight; some in clear glass vessels and some in amber glass containers; some in the presence of air and others in which air was excluded.

It was thought that the alkalinity of such solutions might affect their change on exposure to light, so that another set of experiments was tried, using a 10 per cent. solution made acid with sulphuric acid.

The results were similar to those obtained in the unneutralized solutions. It was noted, however, that in the absence of air it made no decided difference whether the samples were exposed to light or kept in the dark, except in the case where an amber container was used, in which case there appears to be an increase in the amount of nicotine. This latter is inconsistent with the previous experiments and no explanations are offered. It. however, adds to the strength of the belief that light does effect a change in the nicotine, this power of causing deterioration, however, being limited to light of short wave-lengths.

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[243] *Loc. cit.*

A decided change in color of the solutions was also noted. The colors were compared with standard nesslerized ammonia solutions similar to those used to determine the amount of ammonia in water.

Two experiments were tried with nicotine solutions exposed in quartz flasks to ultraviolet light.

A portion of a 0.1 per cent. solution was put in a quartz Erlenmeyer flask five centimetres from an interrupted spark driven by a high-frequency current for fifteen minutes. A slight but decided decrease in the amount of nicotine was found.

A sample of a 40 per cent. nicotine solution (commercial) in a small quartz Erlenmeyer flask was placed five centimetres from an iron arc for thirty minutes. The sample, when analyzed after the exposure to the light, showed a slight but decided increase in the amount of nicotine present.

As facilities for repeating these last two experiments were not available, little value can be attached to them. The former indicates a decrease in the amount of nicotine—a fact contradicted by the results of the latter, in which the conditions were similar, but not identical. It is to be noted that the latter was carried out with a commercial sample which contained oils; and in view of the work of Inghilleri, and Paterno and Maselli, before mentioned, who reported a synthesis of alkaloids by action of light, an hypothesis to account for the apparent increase in nicotine by a synthesis of an alkaloidal substance from such oils, or even some change in the nicotine itself, is not untenable.

Since the basic properties of nicotine are attributed to the pyridine ring, it was thought interesting to undertake an experiment to show whether light had any noticeable action on pyridine. With this end in view, experiments were carried out, which correspond in their essential particulars to those reported above, using pyridine and pyridine solutions instead of nicotine, and it was found that sunlight produces a change in pyridine solutions.

The changes in pyridine were indicated by the results of quantitative analysis by the method by K. E. Schulze.[244]

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[244] *Berichte*, **20**, 3391 (1887). See Treadwell, F. P., and Hall, William F., "Analytical Chemistry," vol. 2, p. 447.

Calcium Carbide and Nitrogen.

An attempt was made to determine whether there was any action between calcium carbide and nitrogen under the influence of ultraviolet light. The calcium carbide was placed in a quartz container, the supernatant air being replaced by nitrogen. The source of light was an iron arc backed by a nickel reflector. There was no apparent reaction, as a manometer connected with the cell showed no change in pressure when the temperature conditions were taken into consideration, and a test for ammonia on treating the product with hot water gave negative results.

Hydrogenation of Oleic Acid.

Experiments were performed to ascertain if there would be an acceleration of the hydrogenation of oleic acid under the influence of the rays from an iron arc. The hydrogen, generated in a Kipp apparatus by the action of hydrochloric acid on zinc, was purified by washing with lead acetate and with sulphuric acid and led into a quartz flask which contained the oleic acid. A long air condenser was passed through the stopper with which the flask was supplied. An iron arc was placed 1.5 centimetres from the flask, and exposure was allowed to proceed for six hours. The iodine numbers of the acid before and after treatment were determined with the following results:

That there is no acceleration in the hydrogenation of oleic acid when hydrogen acts on the acid in the presence of rays from an iron arc under ordinary conditions of temperature and pressure, as blank experiments have shown an amount of saturation equivalent to that found in this trial.

In consideration of repeated references to the ionization of hydrogen gas it is to be noted that hydrogen is found to occur in the following forms: H, H_2, $H+$, $H-$, H_2+;[245] neutral atomic hydrogen, neutral molecular hydrogen, atomic hydrogen bearing a positive charge, atomic hydrogen bearing a negative charge, and molecular hydrogen bearing a positive charge.

As McClung[246] and Thompson[247] have shown that a charged gas can be carried along a tube some distance before it loses its charge, it was throught that an attempt to hydrogenate oleic acid by means of hydrogen made active by a silent electric discharge before being passed into the acid might yield evidence of value in proving the presence or absence of actively charged hydrogen.

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[245] Thompson, *loc. cit.*

[246] "Conduction of Electricity through Gases and Radio-activity."

[247] "Conduction of Electricity through Gases."

The hydrogen generated as in the previous experiments was led through a Siemens ozonizer before it was passed into the oleic acid, which was held in a large test-tube. This tube was immersed in a calcium chloride bath. The temperatures selected for tests were, 20°, 125°, and 200°.

In some of the tests the ozonizer was operated by an induction coil capable of producing a three-centimetre spark, while in others a coil capable of producing a five-centimetre spark was used.

The experiments showed:

1. That oleic acid may be partially saturated by passing in hydrogen at approximately atmospheric pressure at ordinary temperatures;

2. That the action may be increased by heat; and

3. That it cannot be accelerated by activating the hydrogen by passing it through ozonizers under the conditions here mentioned.

SUGGESTIONS.

The observations made above, and experiments reported, are to be considered as preliminary only. Few as they are, they open an almost inexhaustible field for research. If attention is confined to the formation of chloracetic acid alone, which is commercially important because it takes part in the formation of indigo by one of the most successful manufacturing processes, one has only to reflect on the question of possible difference in behavior of chlorine from different sources,[248] and the different catalyzers and quantity and quality of illumination, and it may be added that chlorine itself is used as a catalyzer,[249] without considering conditions of temperature and pressure, to see that much more may be done.

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[248] Cf. Russ, *loc. cit.;* Schluederberg, *J. Phys. Chem.,* 12, 574–631 (1908); Fabinyi-Klausenburg, *Ion.,* 1, 70–71; *Z. Ech.,* 503 (1902); Ludlam, *loc. cit.;* Baskerville and Riederer, *loc. cit.*

[249] Weigert, *Z. Elecktrochem.,* 14, 591 (1908); Burgess and Chapman, *loc. cit.*

It would be interesting also to try variations of the above experiments on acetic acid, benzene, and toluene, where the acetic acid, benzene, or toluene is in the vapor phase.

Furthermore, it would be interesting to conduct experiments on the activation of gases under conditions where the intensity of electric energy or light energy, as well as the distance the gas passes after activation, could be varied.

It is probable that valuable results would be obtained in many cases where attempts are made to use light as a source of energy in accelerating a chemical reaction if particular attention were paid to the absorption spectra of the reacting substances, and it is not unlikely that investigations of the effects of light present under the manufacturing conditions existing, where explosives are prepared and handled, may prove of value.

GENERAL SUMMARY.

In this work evidence is brought forth to show, first, that the well-established belief that certain chemical reactions are accelerated by light is justified, and that such effects are more marked in the presence of ultraviolet light than in the presence of light of shorter wave-length; secondly, the previously scattered evidence has been collected relative to the hypothesis that radiant heat, light, and electricity are similar from a purely physical standpoint and that they produce similar chemical changes, and additional evidence has been obtained.

By studying the effect of light on the reactions taking place between chlorine and acetic acid it was found:

1. That monochloracetic acid could be obtained under the influence of rays from an iron arc at the temperature of the steam bath when no catalyzer is used.

2. That a greater quantity of chloracetic acid could be obtained under the influence of the rays from an iron arc at the temperature of the steam bath if red phosphorus was used as a catalyzer than when no catalyzer was used.

3. That chloracetic acid, chlorination products of benzene and of toluene could not be obtained under the influence of the rays from a projection lantern.

4. That chloracetic acid and chlorination products of benzene could not be obtained from chlorine activated by the use of the rays emanating from a quartz mercury arc before passing into

acetic acid or into benzene, but that chlorination products of toluene could be obtained under similar conditions.

5. That chlorination products of benzene and of toluene could be obtained at room temperatures under the influence of the rays from an iron arc.

6. That chlorination products of benzene and of toluene could not be obtained from chlorine which was led through a Siemens ozonizer before being passed into benzene.

By a study of the effects of light on trinitrotoluene it was found:

1. That trinitrotoluene was decomposed by sunlight.

2. That ultraviolet rays are more active in decomposing trinitrotoluene than rays of longer wave-length.

3. That the change produced when trinitrotoluene is exposed to light is due to oxidation.

An unsuccessful attempt was made to form a chemical compound from nitrogen and calcium carbide under the influence of ultraviolet light.

By studying the effects of light on nicotine solutions it was found:

1. That there is a change in nicotine content when nicotine solutions are exposed to sunlight.

2. That this change is more marked in the presence of air—a fact which indicates an oxidation process.

3. That this power of causing the change is limited to light of short wave-lengths.

4. That ultraviolet light produces a change in the nicotine in nicotine solutions.

5. That sunlight produces a change in the pyridine in pyridine solutions.

6. That the alkalinity of nicotine solutions does not affect the reactions due to light.

By a study of the effect of ultraviolet light on the reaction taking place between oleic acid and hydrogen under the influence of light it was found:

1. That oleic acid may be partially saturated by passing in hydrogen at approximately atmospheric pressure at ordinary temperatures;

2. That the action may be increased by heat; and

3. That it cannot be accelerated by activating the hydrogen by passing it through ozonizers under the conditions here mentioned.

Attention is called to the fact that, from a consideration of the results obtained in experiments where attempts were made to activate gases before their contact with the liquids under consideration, it may be inferred either that ionization of the gas was not obtained or that ionization is not the condition essential for promoting the change.

It is with the greatest pleasure that I express my appreciation of the advice and encouragement received from Prof. Charles E. Munroe and Prof. N. Monroe Hopkins during the course of this work.

Laboratories of the George Washington University,
May 26, 1917.

Heating Buildings with Sprinkler Systems. E. D. Densmore. (*Quarterly of the National Fire Protection Association,* vol. xi, No. 2, p. 168, October, 1917.)—The increasing use of automatic sprinklers in modern commercial industrial buildings has led to the development of the sprinkler system for heating purposes. As is well known, the sprinkler system consists in general of a series of pipes which cover uniformly the ceilings of all floors. If the water which is maintained in the system can be heated and circulated, evidently the sprinkler piping can be used for heating. One fundamental objection is that the sprinkler head which is in ordinary use will melt at the temperature necessary for the water to be used for heating purposes. This melting of the sprinkler head is prevented by means of a U-connection through which the hot water cannot circulate. In practice it has been found that a bend in the horizontal nipple carrying at the end the upright sprinkler head will prevent the head from melting.

The connections of the hot-water heating system with the sprinkler piping are exceedingly simple and need not change the sprinkler piping in any way. The hot-water heater may be located in any convenient place. From the hot-water heater a hot-water supply pipe is run and connected to the foot of the sprinkler riser inside the sprinkler alarm valve. It is advisable to provide an ordinary stop valve at this point so that the hot-water supply may be entirely shut off from the sprinklers when necessary. Between the hot-water connection to the riser and the sprinkler heads no changes are made, the riser, laterals, and distributing pipes being installed in the usual way. Many successful installations have been made, and apparently no fundamental difficulties have been encountered over a period of several years in operation.

THE METALLURGY OF TITANIUM.*

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7. TITANIUM IN THE METALLURGY OF IRON.

General Statement.—The effect of titanium on cast iron has been the subject of much discussion; not a great amount of data is available for the accurate solution of the question, but the probabilities are that the action of the metal has quite contradictory effects. This is presumed to arise from its varying action with the different metalloids. In an extensive paper in 1912 before the American Institute of Mining Engineers, Bradley Stoughton recorded data pertinent to the effect of titanium on the strength of cast iron. One particular point is to be noted from his findings, for the reason that it stands forth very prominently, and that is that titanium unquestionably reduces the chill. This should not be unexpected from what is known of the action of the metal—it being one of the strongest deoxidizers known, and it further has a high chemical affinity for both sulphur and nitrogen. The question logically arises: Why does titanium reduce chill? This is readily answered. The elements oxygen and sulphur (and nitrogen, probably) are productive of chill, and titanium, by removing them, consequently removes their chill action. This shows how the chill is modified and, further, why the strength of castings is lower. The titanium not only removes the sulphur but also the oxygen.[79] The effect of titanium in reducing chill in cast iron is overcome by the use of an increased proportion of manganese for purposes of restoration—and this is decidedly met with disapproval. It appears, on the whole, that not much benefit can arise from using titanium in the metallurgy of cast iron, but recently its use has been recommended by Doctor Moldenke, the American foundry expert, as worthy of employment for the removal of nitrogen and oxygen where special cast irons are to be produced. Some metallurgists held for a long time that titanium rendered cast iron tough—probably, for one reason, because the well-known pig iron of Upper Styria contains a small percentage of the metal. However, steel made therefrom rarely showed any titanium content on analysis, because of the strong affinity of the element for oxygen.

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* Concluded from page 650, vol. 184, November issue.

[79] The effect of small amounts of oxygen in cast iron is to increase its strength and resistance to shock. Oxygen to the amount of but 0.06 per cent. gives cast iron a tensile strength of 3500 pounds per square inch, as compared with 2500 pounds per square inch for otherwise similar non-oxygenated iron. Note Johnson, W. McA., "A Chemical Explanation of the Effect of Oxygen in Strengthening Cast Iron," *Bull. A. I. M. E.,* February, 1916, pp. 233–235.

How Titanium is Used in Iron Metallurgy.—In iron foundry practice, the usual method of employing titanium is to scatter a predetermined amount of a titanium alloy (ferro-titanium or ferro-carbon titanium, as the case may be) along the runner prior to tapping. Upon tapping the cupola, the titanium alloy is washed into the ladle with the stream of iron. As in steel practice, time should be allowed for the chemical reactions to complete themselves, so that the ladle should be held for about three minutes before pouring. Also, as in steel practice, care should be taken so that the slag be not allowed to come in contact with the alloy, as slag attacks the alloy with very great avidity, thus destroying its function. Iron may also be treated in the ladle by adding the titanium alloy to the ladle either before or during tapping. In small hand ladles it is an easy matter to stir the iron with a rod in order to thoroughly incorporate the alloy into the molten bath. For usual deoxidizing purposes, about two to four pounds of a 15-per cent. titanium alloy per ton of iron will be requisite and sufficient.

Effect of Titanium Additions to Iron.—L. Treuheit[80] experimented with the effect of additions of 10 to 15 per cent. titanium and 25 per cent. titanium alloys on iron and arrives at the conclusion that the benefits derived from their use are small. The benefits usually claimed as resulting from titanium treatment of cast iron are summed up as follows:

1. An improvement in machining qualities of the iron;
2. An increase in the hardness of chill;
3. An increase in soundness of castings;
4. An increase in the strength; and
5. That but extremely small amounts of titanium are needed to produce the results given in 1; 0.04–0.05 per cent. titanium being claimed to be effective.

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[80] Treuheit, L., *Stahl und Eisen*, vol. xxx, pp. 1192–1201.

Evidently the first two cannot occur together in the same iron,[81] and the variation in cast-iron samples from the same melt is often so great that it is difficult to say when improvements have really followed the titanium treatment. The chief, and seemingly the only, value of titanium in the treatment of iron lies in its ability to deoxidize the metal. The metal undoubtedly scavenges from the product of the cupola or the air-furnace oxides and occluded gases, as well as nitrides. On this basis, a certain given amount of titanium will cleanse any given iron; any less will be insufficient, while any more will not make the iron better. Sufficient titanium should be added to effect a complete deoxidation and denitrogenation of the metal. However, it is a waste of money to treat a sound metal, as no improvement can be gained in this case unless the composition of the metal is altered. Large iron castings treated with carbon-free ferro-titanium are illustrated in Figs. 22 and 23.

Titanium in the Blast Furnace.—This subject has been dealt with at some length in previous paragraphs. Suffice it to indicate here that titanium may be present to the extent of about one per cent. when the burden is titaniferous, but the element is not known to exert any particular influence on the quality of the iron. When such metal is converted into steel, the titanium is completely eliminated.

Titanium in the Foundry.—Moldenke has set forth the results of his experiments made to show the influence of titanium upon cast iron in his paper of 1908 before the American Foundrymen's Association.[82] Two series of irons were made, white and gray, and the results of his work are tabulated for brevity in Table V, page 889.

Casual examination of these results indicates that there was a distinct advantage obtained by the addition of a certain small percentage of titanium, in the case of the gray iron, but that larger additions did not result in any additional benefit. Regarding the white irons, a small advantage appears to have been secured. The above worker insists that the titanium addition is

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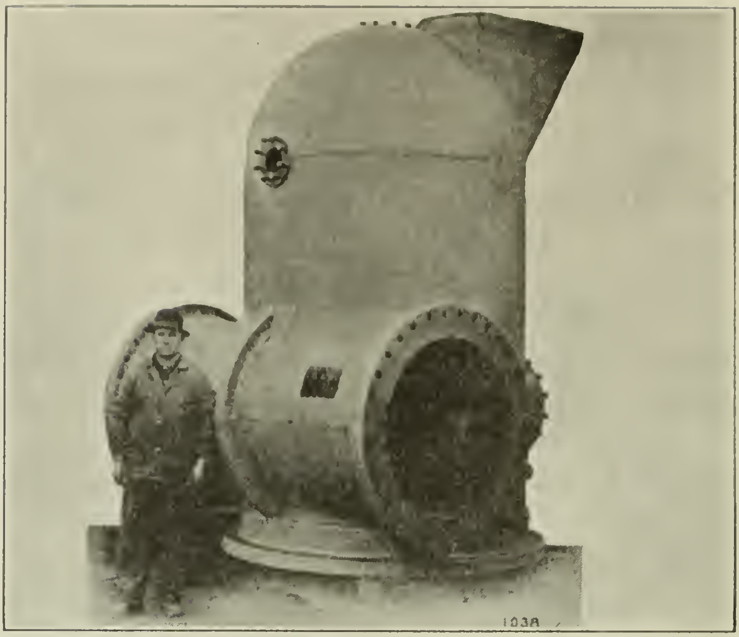
[81] "The claim made that titanium reduces the amount of chill and at the same time makes a harder chill is preposterous" (private communication, J. E. Johnson, Jr., May 15, 1917).

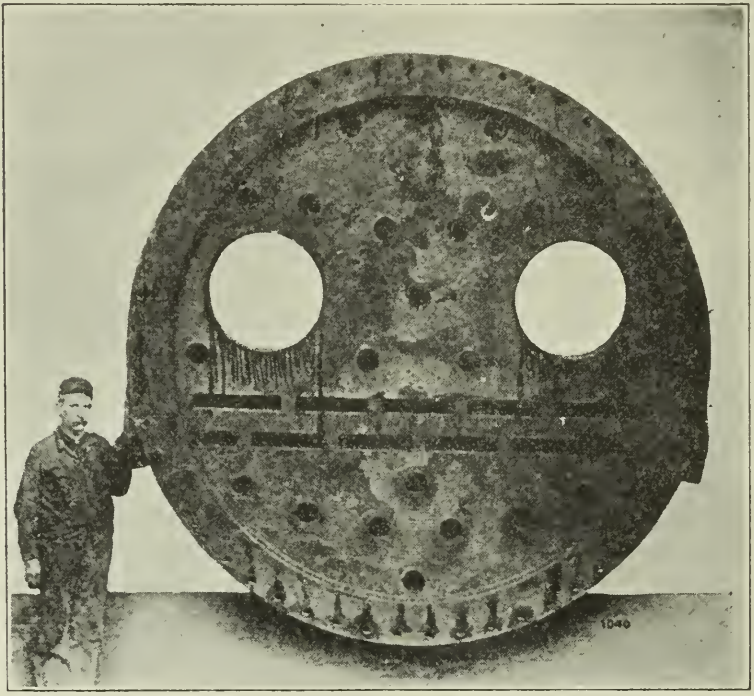
[82] Moldenke, R., "Titanium in Cast Iron," *Trans. A. F. A.*, 1908, vol. 17, pp. 57–64.

FIG. 22.



Large cast-iron cylinder head weighing 13,370 pounds treated with carbon free ferro-titanium. (After Goldschmit Thermidt Company.)

FIG. 23.



ron casting weighing 22,700 pounds treated with carbon-free ferro-titanium. (After Goldschmidt Thermit Company.)

of advantage if no more is used than is required for the purpose of deoxidation.

TABLE V.

Iron used	Per cent. titanium added	If carbon added	Broke at pounds	Deflection
Gray machinery	None	No	2020	0.09
Gray machinery	0.05	No	3100	0.09
Gray machinery	0.05	Yes	3070	0.10
Gray machinery	0.10	No	3030	0.09
Gray machinery	0.10	Yes	2990	0.095
Gray machinery	0.15	Yes	3190	0.100
White iron	None	No	2050	0.05
White iron	0.05	No	2400	0.05
White iron	0.05	Yes	2420	0.05
White iron	0.10	Yes	2400	0.05
White iron	0.15	Yes	2520	0.06

Titanium in Gray Iron.—Gray cast-iron castings normally contain about 2 per cent. or more graphite and less than 1.5 per cent. combined carbon, while the total amount of impurities present will usually be: Silicon, 0.75 to 3 per cent.; manganese, 0.30 to 0.70; phosphorus, 0.5 to 1.5, and sulphur, up to 0.20 per cent. The effect of titanium is to reduce the oxygen, nitrogen, oxides, and nitrides commonly present, and to eliminate blowholes, thereby tending towards the production of sound metal.

Titanium in Malleable Cast Iron.[83]—As is well known, malleable cast iron is produced, as indicated in the footnote, from white cast iron by either the "black-heart" or the "white-heart" process. Silicon must be low in the original iron in order that the carbon may be in the combined form as cementite. Titanium acts in a manner analogous to that of silicon; viz., it will throw down graphite and prevent the formation of Fe_3C. However this may be, the titanium will be oxidized, so that if used in small amounts its beneficial cleansing action will be secured without its entering the metal. The use of titanium alloys in the production of white cast iron for conversion into malleable castings is as yet in the experimental stage, and no data are available.

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[83] Malleable castings are cast as brittle white cast iron and then made malleable by the conversion of most of the combined carbon from Fe_3C into graphite, or by oxidizing the combined carbon, or by both. The illegitimate term "semi-steel" is an indefinite trade name used at times for malleable castings. The term "semi-steel" has no meaning and should not be recognized as having any significance.

Effect of Titanium on Chill.—The effect of titanium on chill has been indicated in the experiments of Moldenke made at the Keystone Car Wheel Works, Homestead, Pa. An iron which gave a depth of chill of 1.5 inches, not treated by titanium, showed but one inch in depth of chill when treated. Tests of the chilled part gave the results in Table VI.

TABLE VI.

Chilled iron	Pounds per square inch compression	Hardness
Treated	298,000	557
Untreated	173,000	445

An addition[84] of a one per cent. titanium alloy to a chilled iron car wheel made the metal closer grained and freer from blowholes, as well as stronger in the flanges and rims.

Effect of Titanium on the Magnetic Properties of Iron.—K. P. Applegate[85] has ascertained the effect of titanium on the magnetic properties of iron. Pure Swedish charcoal iron was treated by a 15 per cent. titanium alloy supplied by The Titanium Alloys Manufacturing Company, and with a 20 per cent. titanium alloy containing some aluminum supplied by the Goldschmidt Thermit Company. The iron-titanium alloys so secured were subjected to hysteresis tests for comparison, and these conclusions were drawn:

1. Small amounts of pure titanium (less than one per cent.) decrease to a slight extent the hysteresis losses in pure Swedish charcoal iron.
2. An increase in the percentage of titanium causes an increase in the hysteresis loss.
3. Alloys of titanium and iron are not rendered appreciably softer by prolonged annealing at 760° C.
4. The commercial titanium alloys, when dissolved in iron, yielded a metal much poorer in magnetic quality than the alloys containing pure titanium.

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[84] Slocum, C. V., in a paper before the Railway Club of Pittsburgh, *Iron Age*, vol. 83, 1909, p. 1347.

[85] Applegate, K. P., "The Effect of Titanium on the Magnetic Properties of Iron," Rensselaer Polytechnic Institute, Eng. and Sci. Ser. No. 5.

5. Titanium steels are not as good as the present standard silicon steels.
6. Small amounts of pure titanium increase the permeability of pure Swedish charcoal iron.
7. The maximum induction of alloys containing titanium was considerably higher than the XI* steel or pure iron samples.
8. The permeability of the titanium specimens was higher, for the same value of H, than the XI* steel or pure iron.
9. The small percentages of pure titanium gave the lowest values for the hysteretic constant when the titanium alloys were considered. These values were, however, not as low as the hysteretic constant for the XI* steel.

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THEORY AND OPERATION OF DR. ZAHM'S PROPELLER COMPUTER.

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Theory.—In designing an aerial propeller by Drzewiecki's method, the blade section is assumed to act like an ordinary aerofoil, and its aerodynamical properties are assumed unchanged, due to the presence of neighboring blade sections. If we lay off along *oa*, in the following figure, the peripheral velocity of a propeller, and along *ab* the velocity of advance, then the hypothenuse *ob* will represent the resultant velocity, and i will be the angle of incidence, A the helix angle for the path of the indicated blade section.

Then the unit thrust T will be given by the equation:

$$T = L \cos A - D \sin A$$

where L and D denote the unit lift and drift of the aerofoil. But from wind-tunnel experiments we know:

$$L = K_y S V^2$$

and

$$D = K_x S V^2$$

where $K_y =$ lift coefficient
$K_x =$ drift

and

$V =$ resultant velocity along the helical path in this case
$S =$ area of aerofoil

If we call T_1 the thrust per unit area, we have:

$$T_1 = K_y V^2 \cos A - K_x V^2 \sin A$$

$$T_1 = K_y V \left(V \cos A - \frac{K_x}{K_y} V \sin A\right)$$

If we construct upon *ob* a right triangle *obe* similar to the triangle *o′b′c′* and project *oe* upon *oa*, we have:

$$og = ob \cos A - be \sin A$$

But since

$$ob = V$$

and

$$be = ob \tan \left(\tan^{-1} \frac{K_x}{K_y}\right)$$

or

$$= V \frac{K_x}{K_y}.$$

Therefore $$og = V\cos A - \frac{K_x}{K_y} V \sin A$$

Og is then equal to the expression included in the parenthesis in the thrust equation, and is called the thrust factor, and the equation then becomes:

$$T_1 = K_y\, V \times og$$

The efficiency of a blade section is expressed by the well-known formula:

$$\text{Efficiency} = \frac{\tan \quad A}{\tan\ (A + G)}$$

where

$$G = \text{gliding angle} = \frac{K_x}{K_y}$$

or

$$\text{Efficiency} = \frac{hg}{og} \div \frac{ge}{og} = \frac{hg}{ge}$$

Construction of the Computer.—The theory upon which the computer is based has been delineated above, and it remains to be put in the form of a chart for practical use.

If we mark on *oy* the velocity of advance, on *ox* the peripheral velocity, both in miles per hour, and upon *ox* erect a number of ordinates having the values of R.P.M. and blade-section radii labelled upon them to correspond to the peripheral velocity shown on *ox*, the resultant velocity in miles per hour is at once indicated by the position and magnitude of *ob* for any combination of values of R.P.M. and velocity of advance. The helical angle *A* is indicated by the angle *ob* makes with *ox*, and its value in degrees is marked on the right-hand border of the chart.

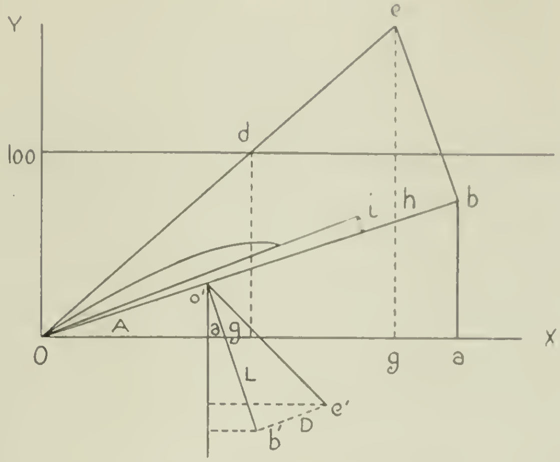
In the thrust equation, if we put V in miles per hour, K_y and K_x in absolute units, we must multiply the equation by a constant, 0.0051, in order to have T_1 in pounds per square foot at standard atmospheric density. Then

$$T_1 = 0.0051\ K_y\ V\ (V \cos A - \frac{K_x}{K_y} V \sin A)$$

To represent *ob* or V in the chart, a line *ob″* is scribed in a piece of celluloid having an L shape, as shown in Fig. 2, and the head of the L is pivoted at *o*, Fig. 1. On *ob″* are marked the values of 0.0051 V, and on *b″e″* the values of $\frac{K_x}{K_y}$ for different angles of incidence. A thread is stretched from *o* to a runner which slides on the celluloid arc *b″e″*. It represents the line *oe* in Fig. 1. A small celluloid T-square, with a black centre line along its length, is placed perpendicular to ob'' in Fig. 2, and is used to represent be in Fig. 1.

Since the efficiency is equal to $\frac{hg}{eg}$ Fig. 1, we drop a perpendicular upon ox from d, the point of intersection of oe (or the thread), with the horizontal line representing the velocity of advance at 100 miles per hour, we have then:

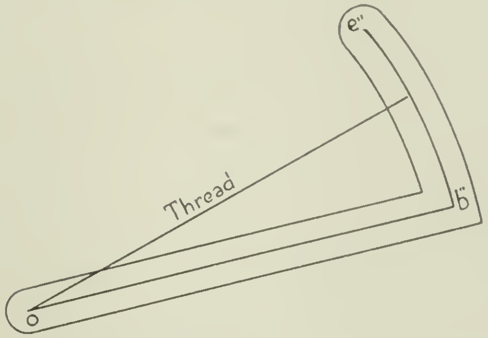
FIG. 1.



$$\text{Efficiency} = \frac{h\,g}{e\,g} = \frac{h^1\,g^1}{d\,\,g^1} = \frac{h^1\,g^1}{100} = h^1\,g^1 \text{ per cent.}$$

The vertical scale for the velocity of advance is therefore also the scale of efficiency in per cent., and the efficiency can be read directly.

FIG. 2.



Having found the values of the thrust factor, efficiency, and 0.0051 V from the chart, the thrust per foot run of blade is:

$T =$ blade width in feet $\times\ T_1 = 0.0051\ V \times K_y \times$ thrust factor $\times$ width . . (1)

The torque L' per foot run is obviously

$$L' = c\,\frac{Va}{N}\,\frac{T}{E} \quad . \; . \; . \; . \; (2)$$

where Va is the forward velocity, E the efficiency of the blade section, N the angular velocity, and c is a constant depending upon the choice of units. If T be pounds, L pound-feet, Va miles an hour, N revolutions per minute,

$$L = 14\,\frac{Va}{N}\,\frac{T}{E}$$

Before using the computer the aerodynamical properties of the blade sections at different radii and the blade widths must be known. The former may be found in the British Aeronautical Report, Eiffel, and other aerodynamical laboratory reports. A series of aerofoils that have been tested in the National Physical Laboratory in England, and is often used for propeller-blade sections, is found in the British Aeronautical Report, 1911–12.

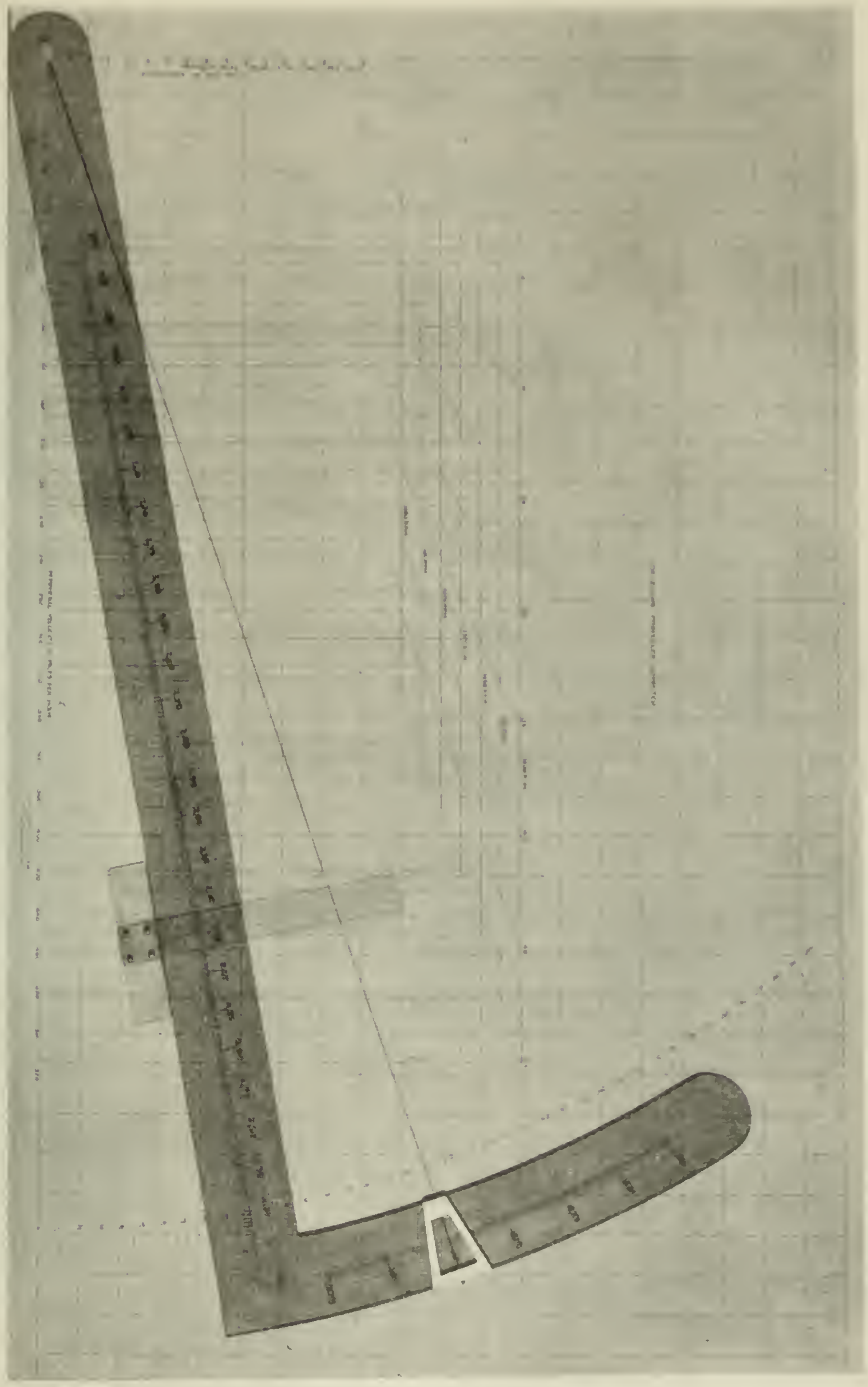
Illustration:

Let $N = 1300$ R.P.M.
$r = 30$ inches
$Va = 90$ M.P.H.

1	2	3	4	5	6	7	8	9	10	11	12
Section in feet	Chord length in feet	Blade axle in degrees	Angle of attack	Blade curve	Lift-coefficient	Drift lift	Section efficiency	0.005 Va	Thrust factor	Thrust per foot run	Torque per foot run
1½											
2											
2½	1.15	23.2	2	5	0.300	0 090	0.780	1.248	224	96.5	120
3											
3½											

In the above table columns 2, 3, and 5 are fixed by the designer, columns 6 and 7 are found from the British Aeronautical Report, 1911–12; columns 4, 8, 9 and 10 are found from the computer, and the last two columns are computed by equations (1) and (2).

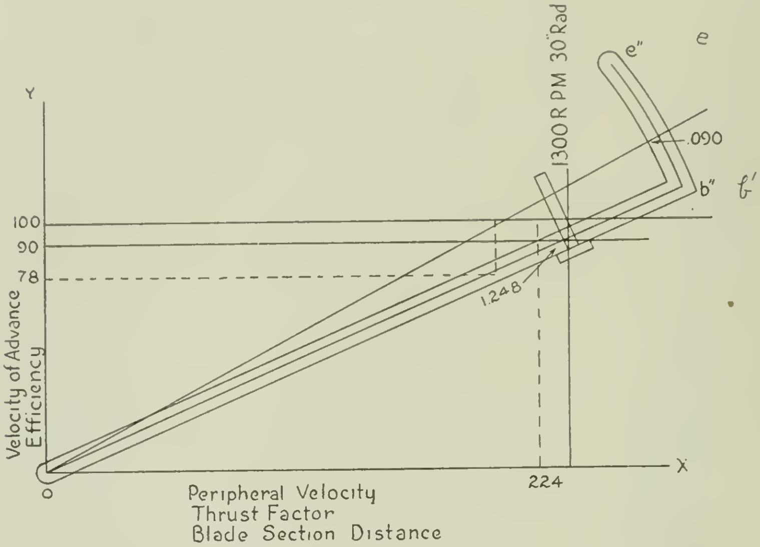
Having found the lift coefficient and $\frac{\text{drift}}{\text{lift}}$ ratio for the given blade section, firstly, swing the L piece until its line ob'' passes through the intersection of the 90-mile line and the 1300



Dr. Zahm's propeller computer.

R.P.M. 30-inch radius line and notice the reading on *ob''*. It is 1.248. Put this value in column 9 in the above table. Secondly, set the small T-square with its edge at the point 1.248, as shown in the diagram, and then swing the thread until it coincides with the 0.090 mark on the $\frac{\text{drift}}{\text{lift}}$ scale. The intersection of the T-square with the thread gives the thrust factor 224 as indicated on *OX*. From the point of intersection of the thread and the 100-mile line drop a vertical line to *ob''* and read the efficiency on the vertical scale, which is 78 per cent. in this case.

Fig. 3.



Then the thrust per running foot of blade is:

$$T = \text{blade width} \times \text{lift coefficient} \times 0.005\ Va \times \text{thrust factor}$$
$$= 1.15 \times 0.300 \times 1.248 \times 244 = 96.5 \text{ pounds}$$
$$\text{Torque per running foot} = 14\,\frac{90 \times 96.5}{1300 \times .78}$$
$$= 120 \text{ foot-pounds}$$

Similarly the thrust and torque of the other sections are found. Plot the thrust, torque, and efficiency curves with radius of the sections as abscissæ. Intergate the areas under the thrust and the torque curves. Then we have the total thrust torque and efficiency for the two-blade screw:

$$\text{Total thrust H. P.} = \frac{\text{Thrust per blade} \times 2 \times \text{Va in feet per second}}{550}$$
$$\text{Total torque H. P.} = \frac{2\,\pi\,n}{33000} \times \text{torque per blade} \times 2$$
$$\text{Overall efficiency} = \text{Thrust H. P.} \div \text{Torque H. P.}$$

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

A SIMPLIFIED METHOD OF WRITING DEVELOPING FORMULÆ.[1]

By C. E. K. Mees.

[ABSTRACT.]

The usual methods of writing developing formulæ make it very difficult to compare different formulæ, so that it is not unusual to find several formulæ which are apparently quite different, but which, if written in the same form, prove to be identical in composition.

In order to facilitate the comparison of formulæ, it is convenient to be able to write a formula in one line, thus enabling a number of formulæ to be written under one another and compared at a glance; the following notation enables this to be done.

The formulæ are expressed in grammes per litre, the water being omitted, then if R stands for the reducing agent, A the alkali, S the sulphite, and B the bromide, the formula is always written in the order R A S B, which is used as a mnemonic. Thus 5–50–50–1 means 5 grammes of reducing agent, fifty of alkali, fifty of sulphite, and one of bromide per litre.

In order to indicate the particular substances used, the reducing agents are represented by initial letters—P for pyro, H for hydrochinon, and so forth; while if no other specification is given, A represents sodium carbonate dry, S sodium sulphite dry, and B potassium bromide; thus P5–15–10–0 represents the following developer:

Pyro	5 gms.
Sodium carbonate (anhydrous)	15 gms.
Sodium sulphite (anhydrous)	10 gms.
Water to	1000 c.c.

Other chemicals are represented by their formulæ or by any other convenient abbreviation, so that the well-known hydrochinon-caustic potash formula used for process plates may be written H12.5–KOH25–Meta25–12.5, this corresponding to:

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* Communicated by the Director.

[1] Communication No. 52 from the Research Laboratory of the Eastman Kodak Company, published in *British Journal of Photography*, 1917, p. 535.

A.	Hydrochinon	12.5 gms.
	Potassium metobisulphite	25 gms.
	Potassium bromide	12.5 gms.
	Water	500 c.c.
B.	Caustic potash	25 gms.
	Water	500 c.c.

Use equal parts *A* and *B*.

A convenient means of classifying developers containing a mixture of metol and hydrochinon as the reducing agent has been in use for some time in our Research Laboratory.

As a result of a series of measurements it was found that the formula 5–25–55–1.5 was most convenient and suitable for these developers, and this formula was entitled MQX, the suffix *X* representing the percentage of the reducing agent, which is metol; thus MQ_{20} corresponds to 20 per cent. metol, 80 per cent. hydrochinon, or a developer of the formula:

Metol	1 gm.
Hydrochinon	4 gms.
Sodium carbonate	25 gms.
Sodium sulphite	75 gms.
Potassium bromide	1.5 gms.
Water to	1000 c.c.

MQ_0 represents the same formula without metol and with 5 grammes of hydrochinon, MQ_{50} corresponds to 2½ grammes metol and 2½ grammes hydrochinon, and MQ_{100} to 5 grammes metol without hydrochinon.

The most useful members of this series have proved to be MQ_0, MQ_5, MQ_{25}, MQ_{50}, and MQ_{80}.

THE FRANKLIN INSTITUTE

OFFICERS AND MEMBERS OF COMMITTEES WHO ARE NOW IN THE ACTIVE MILITARY OR NAVAL SERVICE OF THE UNITED STATES GOVERNMENT.

Name and rank	Position	Branch of service	Location
Major R. B. Owens	Secretary	Signal Corps	France
Capt. T. F. Clark	Board of Managers	Field Artillery	Camp Meade
Mr. W. C. Wetherill	Board of Managers	Navy Aviation Dept.	Boston
Lieut. H. B. Allen	S. & A. Committee	Ordnance Dept.	France
Lieut. E. L. Clark	S. & A. Committee	Signal Corps	Camp Devens
Major G. S. Crampton	S. & A. Committee	Director of Field Hospitals	Camp Hancock
Lieut. T. R. Parrish	S. & A. Committee	Signal Corps	Washington
The following are doing special Government work:			
Mr. Charles Day	Board of Managers	Member of Commission to study shipping situation	London
Dr. T. D. Cope	S. & A. Committee	Research work	Washington
Mr. F. H. Gilpin	S. & A. Committee	Testing Department	Picatinny Arsenal

Certain definite activities have been undertaken by the Institute, as follows:

1. An office for the registration of men wishing to enter the Aviation Section of the Signal Corps was conducted during the summer by Dr. George F. Stradling, member of the Institute. Registration is still being carried on, and up to the present time 837 applications have been received and forwarded to the proper authorities.

2. Another direction in which the Institute has been of service is in the making of searches and submitting reports on various subjects to the National Research Council.

3. During the summer, at the suggestion of the Shipping Board of the United States, the President of the Institute authorized the organization of a School of Navigation. This School was carried on for several weeks at the Institute, and was then transferred to other quarters, at the University of Pennsylvania.

4. In response to a request from the Federal Board for Vocational Education, of Washington, D. C., the Institute has recently organized and is now carrying on a school for the training of men in receiving and sending wireless messages. Membership in the classes of this school is restricted to conscripted men who are sure to be included in the next or following calls, and whose physical eligibility for the service has been established.

PROCEEDINGS OF THE STATED MEETING HELD WEDNESDAY, NOVEMBER 21, 1917.

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 21, 1917.

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to membership since last report, 10.

Mr. Louis E. Levy, Acting Chairman, Committee on Science and the Arts, reported the condition of the work of the committee. The Chairman announced that the first business of the meeting was the presentation of the medals recommended for award by the Committee on Science and the Arts. A telegram was read from Mr. Thomas Bilyeu, of Astoria, Ore., stating that he was occupied with war duties which would prevent him from attending the meeting, and requesting that the ceremonies in connection with the presentation of the John Scott Medal to him be postponed for one month in order that he might make arrangements to be present.

Mr. Louis E. Levy was then recognized and described the coin sorting, counting, and recording apparatus of the International Money Machine Company, to whom was awarded the Edward Longstreth Medal of Merit.

The President presented the medal and accompanying certificate to Mr. H. D. Hoffman, representative of the company. Mr. Hoffman, in accepting the award, expressed the appreciation of his company for the honour conferred upon it.

Mr. Levy was again recognized and described the Chainomatic Balance, a device for making weighings more accurately and rapidly than heretofore. He introduced Mr. Christopher A. Becker, of the firm of Christian Becker, Inc., of New York City, inventors of the Chainomatic Balance, to whom had been awarded the Edward Longstreth Medal of Merit. The medal was presented to Mr. Becker, who thanked the Institute for the recognition bestowed upon them.

M. C. Whitaker, M.Sc., D. Chem. Eng., Vice-President, U. S. Industrial Alcohol Company, New York City, N. Y., presented a communication on "Industrial Alcohol." The present state of development of the industrial alcohol industry in the United States, compared with developments in foreign countries, was discussed. Mention was made of the raw materials now used and prospects for future development of new sources of supply. The technical principles and problems involved in the manufacture of alcohol from various raw materials were described, and a forecast was made of the lines for future development, both in manufacture and in the use of the products. A comparison was made of the government regulations and restrictions which tend to develop or retard the alcohol industry in various countries. The subject was fully illustrated by lantern slides.

After a brief discussion the thanks of the meeting were extended to Doctor Whitaker for his interesting paper.

Adjourned.

GEORGE A. HOADLEY,
Acting Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, November 7, 1917.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 7, 1917.

MR. LOUIS E. LEVY, *Chairman pro tem.*

The following reports were presented for first reading:

No. 2693.—Dressler Tunnel Kiln. Report referred back to Sub-Committee for further information.

No. 2701.—Talbot Air Lift. Report referred back to Sub Committee for further information.

No. 2705.—Levy Hæmocytometer.

GEO. A. HOADLEY,
Acting Secretary.

SECTIONS.

Section of Physics and Chemistry.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, October 25, 1917, at 8 o'clock, with Dr. Gellert Alleman in the chair. The minutes of the previous meeting were read and approved.

David Fairchild, Sc.D., Agricultural Explorer in Charge of the Office of Foreign Seed and Plant Introduction, United States Department of Agriculture, Washington, D. C., delivered a lecture on "The Palate of Civilized Man and Its Influence on Agriculture." The influence of custom and fashion on the dietary was discussed, and a description was given of various foreign fruits and vegetables which have been introduced into the United States during the past twenty years. The lecture was illustrated with specimens and lantern slides.

The paper was discussed by Doctors Hoadley, Harshberger, C. A. Smith, and others. On motion of Mr. Louis E. Levy a vote of thanks was extended to Doctor Fairchild. The meeting then adjourned.

JOSEPH S. HEPBURN,
Secretary.

Electrical Section.—A joint meeting of the Section and the Philadelphia Section, American Institute of Electrical Engineers, was held in the Hall of the Institute on Thursday, November 1, 1917, at 8 o'clock P.M.

In the absence of the chairmen of both sections, the meeting was presided over by Doctor Carl Hering.

W. F. G. Swann, A.R.C.S., D.Sc., Chief of the Physical Division, Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D. C., delivered a lecture on "Atmospheric Electricity."

The lecturer reviewed our present knowledge and the theory of atmospheric ionization and performed experiments showing how this ionization was increased by external causes, as by a flame and by the rays emanating from a glass tube containing radium. The radio-active materials in the soil were shown to be one of the sources for maintaining the atmospheric ionization, and comparisons were shown of figures taken over land and over sea, the latter being obtained on one of the recent voyages of the non-magnetic ship *Carnegie* belonging to the Carnegie Institution.

The lecturer included slides of this vessel and a description of the apparatus used in making the measurements.

The evening was concluded by a brief consideration of G. C. Simpson's theory of thunderstorms.

The thanks of the meeting were extended to the speaker.

H. CALVERT,
Secretary.

Mining and Metallurgical Section.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, November 8, 1917, at 8 o'clock, with Dr. Harry F. Keller in the chair. The minutes of the previous meeting were approved as read.

Edward W. Parker, Director of the Anthracite Bureau of Information, Wilkes-Barre, Pa., late Statistician in Charge of the Division of Mineral Resources, United States Geological Survey, presented a communication on "The Problem of Coal Supply." The coal resources of the United States were described with respect to their location, extent, and character. The relation between population and coal production was pointed out. Stress was placed on the influence of the coal industry on the industrial growth of the nation. An account was given of the changes in the fuel situation which have occurred as a result of the world war. The address concluded with a series of lantern slides showing past and present-day conditions in the anthracite region.

The paper was discussed at length; a vote of thanks was extended to Mr. Parker, and his communication was referred to the Committee on Publications. The meeting then adjourned.

JOSEPH S. HEPBURN,
Acting Secretary.

Section of Physics and Chemistry.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, November 15, 1917, at 8 o'clock, with Prof. Alexander E. Outerbridge, Jr., in the chair. The minutes of the previous meeting were read and approved.

William Porter White, Ph.D., of the Geophysical Laboratory, Carnegie Institution of Washington, Washington, D. C., delivered an address on "Heat and Temperature Measurement, with Special Reference to Industrial Work." The evolution of the calorimeter was traced, and the good and bad points of each type of instrument were pointed out. The mercury thermometer, resistance thermometer, and thermocouple were described, and the advantages and disadvantages in the use of each were enumerated. The lecture was illustrated with lantern slides.

Doctors Northrup, Hering, White, Professor Outerbridge, Mr. Clamer, and others participated in the discussion. On motion of Mr. Clamer, seconded by Doctor Northrup, a vote of thanks was extended to Doctor White. The meeting then adjourned.

JOSEPH S. HEPBURN,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, November 14, 1917.*)

RESIDENT.

MR. FELIX A. BOERICKE, Bryn Athyn, Pa.
DR. JOHN J. BOERICKE, Merion, Pa.
DR. EDWARD E. MARBAKER, Chemist, 224 South Fifty-ninth Street, Philadelphia, Pa.
MR. E. J. WHITE, Chemist, Ninth and Westmoreland Streets, Philadelphia, Pa.

NON-RESIDENT.

MR. G. EDWARD BARNHART, Signal Corps Aviation School, Cottage B-6, Unit No. 1, Dayton, Ohio.
MR. ENRIQUE BUSTOS, Mechanical Engineer, Baltimore Copper Works, Baltimore, Md.
CAPTAIN AUSTIN L. HODGES, Physicist, Frankford Arsenal, Bridesburg, Philadelphia, Pa.
MR. SAMUEL SPITZ, Inventor, 372 Bellevue Avenue, Oakland, Calif.
MR. JOHN F. WARWICK, Electrical Engineer, Box 3108, Boston, Mass.

ASSOCIATE.

MR. STUART D. KERR, 300 Main Street, Darby, Pa.

CHANGES OF ADDRESS.

MR. JOHN CALDER, Aeromarine Plane and Motor Company, Keyport, N. J.
MR. CLARENCE R. CLAGHORN, Vinton Colliery Company, Claghorn, Delaware County, Pa.
MAJOR A. S. CUSHMAN, 135 South Eighteenth Street, Philadelphia, Pa.
MR. FRED. DENIG, 2166 Fourteenth Street, Troy, N. Y.
MR. FREDERICK A. DOWNES, 414 Widener Building, Philadelphia, Pa.
MR. CHARLES N. FORREST, The Barber Asphalt Paving Company, Maurer, N. J.
MR. HENRY GLOVER, Fairfax Apartments, C-5, Wayne Avenue and School Lane, Germantown, Philadelphia, Pa.
MR. GEORGE R. HENDERSON, Aldine Hotel, Philadelphia, Pa.
MR. EDWIN WALKER KELLY, 312 Wisconsin Avenue, Oak Park, Ill.
MR. GEORGE H. MCFADDEN, 121 Chestnut Street, Philadelphia, Pa.
MR. C. L. MCILVAINE, 191 Hodge Avenue, Buffalo, N. Y.
MR. WILLIAM S. MURRAY, B-1017, Waterbury, Conn.
MR. LAWRENCE T. PAUL, 776 Drexel Building, Philadelphia, Pa.
COL. SAMUEL REBER, Army Building, 39 Whitehall Street, New York City, N. Y.
MR. J. J. RHOADS, 407 West Second Street, Oil City, Pa.
MR. WILLIAM H. RICHMOND, Richmond Villa, Scranton, Pa.
MR. EDWARD RITTENHOUSE, 2561 North Front Street, Philadelphia, Pa.
MR. F. R. WADLEIGH, 24 Broad Street, New York City, N. Y.

MR. SAMUEL T. WAGNER, School House Lane, Germantown, Philadelphia, Pa.
MR. NORMAN T. WHITAKER, 230 Whitaker Building, Washington, D. C.
MR. R. A. WIDDICOMBE, 5647 Kenmore Avenue, Edgewater Station, Chicago, Ill.

NECROLOGY.

Mr. R. B. Kendig, Hawthorne Avenue, Port Chester, N. Y.
Mr. George E. Bartol, Room 58, The Bourse, Philadelphia, Pa.

LIBRARY NOTES.

PURCHASES.

ALT, H. L.—Mechanical Equipment of School Buildings. 1916.
AUDSLEY, G. A. and B.—Art of Polychromatic and Decorative Turning. 1916.
CLEWELL, C. E.—Handbook of Machine Shop Electricity. 1916.
CROFT, TERRELL.—Practical Electrical Illumination. 1917.
FLETCHER, F. M.—Wood-block Printing. 1916.
HARDING, L. A., and WILLARD, A. C.—Mechanical Equipment of Buildings, vol. 2. 1917.
HOMANS, J. E.—Self-propelled Vehicles. 1913.
MARTIN, GEOFFREY.—Industrial and Manufacturing Chemistry, 2 volumes. 1917.
MILLIKAN, R. A.—The Electron. 1917.
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Alabama Geological Survey, Bulletin No. 19, Statistics of the Mineral Production of Alabama for 1915, and Circular No. 3, Concerning Oil and Gas in Alabama. University, 1917. (From the Survey.)
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Clark, Walton, A Century of Light. Philadelphia, 1917. (From the Author.)

Connecticut Telephone and Electric Company, Catalogue No. 26. Telephones for Interior Use. Meriden, Conn., 1917. (From the Company.)

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Didier-March Company, Booklet, Automatic Burning in a Continuous Railroad Tunnel Kiln. Perth Amboy, N. J., 1916. (From the Company.)

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Whiting Foundry Equipment Company, Catalogues Nos. 128, 129, and 131. Harvey, Ill., no dates. (From the Company.)

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Ocean Magnetic Observations, 1905–1916, and Reports on Special Researches, by L. A. Bauer, Director, with the Collaboration of W. J. Peters, J. A. Fleming, J. P. Ault, and W. F. G. Swann. Washington, Carnegie Institution of Washington, 1917. 447 pages, illustrations, tables, plates, quarto. Price $10.

In this volume we have a lucid and complete account of the magnetic surveys of the ocean conducted by the Carnegie Institution on the two vessels, the *Galilee* and its successor, the *Carnegie*. The observing instruments are discussed and portrayed, the methods of observation and reduction are stated, specimen observations are given, and extensive tables present the final results. The charts of the cruises show numerous closed loops intentionally produced in order to facilitate a mathematical attack upon some of the general problems of the earth's magnetism.

It is interesting to read with what success all magnetic substances were banned in the construction of the *Carnegie* except about 600 pounds of springs, valves, etc., entirely essential to the gas producer and the internal-combustion engine. One very practical and immediately available product of the survey is the possibility of correcting the charts of magnetic declination used by mariners. In very many localities these charts are incorrect by less than two degrees. This means that a ship's master, knowing his location on the earth's surface and having such a chart and a mariners' compass, would be able to fix a true north to south line with an error less than two degrees. Near Queen Mary's Land, southwest of Australia, however, the British and the United States charts were 12 degrees and the German charts no less than 16 degrees in error.

The volume is splendidly illustrated. The frontispiece, a picture of the *Carnegie,* is a delight to the eye. The friends of the Director will be able to recognize his face in another illustration.

It is with a feeling of pride that the volume is laid down. A great and permanent contribution has been made by American science to the world's knowledge of terrestrial magnetism, and the form of presentation is worthy of the contents.

GEORGE F. STRADLING.

NOTIONS GÉNÉRALES SUR LES APPAREILS À REACTION, par Paul Popovatz. Paris, Gauthier-Villars et Cie, 1916. 36 pages, 5½ × 9 inches, paper, 1 franc 50.

Always of the greatest interest, at the present time more than ever before, the subject of propulsion by reaction is one of the highest importance. In both marine and aerial propulsion the greatest progress has been made by the slow process of evolution from experimental data. It is true that formulas for thrust, power, efficiency, and the like have been derived in works on hydraulics and monographs on propulsion; but the problem has not yielded to theoretic treatment as readily as other hydraulic problems, and it has been the practice in important work to design propellers for marine vessels by experiments on models from which the performance of the full-size propeller may be calculated. More recently, however, there has been a disposition to analyze the problem more minutely from a theoretic point of view with the object of establishing dynamical formulas with coefficients more widely applicable than those in common use. Undoubtedly it is only on such a sound basis that a satisfactory theory of design can be established.

The present work is devoted to that end by an analysis of the principles of reaction apparatus based upon the fundamental formulas of momentum and kinetic energy. Throughout the work the deductions of the relationship of thrust, power, and efficiency are made with the greatest clarity from carefully considered premises, leaving the reader in no uncertainty as to the significance of the conclusions.

Among the features of particular interest are those relating to a rational mode of estimating efficiency and a theoretical deduction of the diameter of the jet obtained from a propeller of given diameter, a quantity previously determined only by experiment. On the question of efficiency, the author points out that most writers consider efficiency from the standpoint of the product of velocity of the vessel and thrust. This mode of rating efficiency is obviously, as he states, wholly inapplicable when the vessel is stationary or lifted by the reaction of a jet; and he lays stress on the value of considering efficiency in terms of jet-velocity for comparing the performance of vessels operating under varying conditions of motion.

This brief work is a model of logical deduction of the principles of jet reaction and should prove a material aid in placing the design of propelling apparatus on a rational basis.

LUCIEN E. PICOLET.

THE J. E. ALDRED LECTURES ON ENGINEERING PRACTICE, Department of Engineering, Johns Hopkins University. Baltimore, The Johns Hopkins Press, 1917. 246 pages, 6 × 9 inches, paper.

It has long been the custom of engineering schools to include in their curricula a number of lectures on subjects of applied engineering by engineers actively identified with professional practice, a procedure upon whose educational value it is scarcely necessary to dwell. The course maintained in the Department of Engineering of Johns Hopkins University is one feature of a general plan, made possible by the gift of Mr. J. E. Aldred, for furthering and improving undergraduate instruction in the methods and problems in the practice of engineering.

The lectures deal, therefore, with everyday working methods of design, construction, and operation rather than with underlying theory. During the year 1916–1917 three lectures each have been given on the general subjects of civil, electrical, and mechanical engineering. They cover hydraulic and steam power projects and gas manufacture; transportation; structural design; sanitation; and corporate and public utility finance. The lectures will be given in succeeding years, in accordance with the same general plan. They are given in the afternoon and are open to the public.

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PUBLICATIONS RECEIVED.

Lubricating Engineers' Handbook: A reference book of data, tables and general information for the use of lubricating engineers, oil salesmen, operating engineers, mill and power-plant superintendents and machinery designers, etc., by John Rome Battle (B.S. in M.E.).—333 pages, illustrations, plates. 8vo. Philadelphia and London, J. B. Lippincott Company, 1916. Price, $4.

Laboratory Guide of Industrial Chemistry, by Allen Rogers, in charge of Industrial Chemistry, Pratt Institute, Brooklyn, N. Y. Second edition, entirely rewritten and enlarged. 212 pages, illustrations, 12mo. New York, D. Van Nostrand Company, 1917. Price, $2.

El Levantamiento de la Carta Militar de la Republica Mexicana. Proyecto que presentan a la consideracion del Ciudadano Presidente de la Republica los Ingenieros General Maximiliano Klos y Teniente Coronel Francisco Diaz Babio. 63 pages, illustrations, plates, 8vo. Mexico, 1917. Price, $3.

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U. S. Department of Agriculture: Circular 79, Emergency Fuel from the Farm Woodland, by A. F. Hawes, Extension Specialist. 8 pages, 8vo. Washington, Government Printing Office, 1917.

*Natural Reproduction from Seed Stored in Forest Flo*or, by J. V. Hofmann. Reprinted from *Journal of Agricultural Research,* vol. xi, No. 1. 26 pages, plates, map, 8vo. Washington, Government Printing Office, 1917.

U. S. Bureau of the Census: Census of Manufacturers, 1914. Agricultural implements. Prepared under the supervision of W. M. Stewart, chief statistician of manufactures. 12 pages, quarto. Washington, Government Printing Office, 1917.

Etching Steel Electrically. ANON. (*Scientific American,* vol. cxvii, No. 18, p. 334, November 3, 1917.)—An electric pencil or "etchograph" for writing or drawing on a piece of steel, so that the marking is etched deeply and permanently, has been perfected by William Brester, of New York City. The device consists of a pencil member and a step-down transformer which can be connected to an alternating-current socket. From the secondary or low-voltage side of the transformer one lead is connected to the work, the other to the pencil member. The pencil has a hard-rubber handle and a metal clamp which holds a short length of ordinary copper wire.

As the electric pencil is drawn over the steel surface of the work, great heat is developed at the point of contact. The etching depth can be readily varied by means of a rheostat. Operating on a 110-volt, 60-cycle circuit, the transformer requires a current of 1½ to 2 ampères and delivers about 20 ampères at 2 volts to the copper point of the pencil. It is said that the etchograph is adapted to marking either iron or steel, and all classes of high-speed carbon and machine steel, whether in the hardened or soft condition.

CURRENT TOPICS

Plumbago Crucibles. Anon. (*Engineering and Mining Journal*, vol. 104, No. 18, p. 797, November 3, 1917.)—The manufacture of plumbago crucibles has been seriously affected by conditions due to the present war. The disturbances have extended to the users of crucibles, involving increased costs and in some cases reducing output because of the shortage of crucibles of the proper quality.

The important and essential ingredients of plumbago crucibles are the plumbago and the clay which serves to hold the crucible together during manufacture and in use. The supply of plumbago comes largely from the Island of Ceylon. In October, 1914, the British Government placed an embargo on plumbago exports from Ceylon lasting more than four months. This exhausted the reserve stocks of American manufacturers. After the embargo was raised shipments were generally regular enough to meet requiremnets except for short periods. Before the war all the clay for plumbago crucibles was imported almost exclusively from the town of Klingenberg, in the western part of Germany. The clay is remarkably clear and uniform, and the deposit large enough to supply all demands that have been made upon it.

Soon after the war Germany prohibited the shipment of this clay, and it became necessary to find a substitute. In trying out different mixtures the plan was adopted to make trial lots of six crucibles from each blend of clay. As it takes from two to three months to make and burn crucibles and get results from tests of users, progress is slow. While before the war 25 to 30 heats were secured from each crucible, the first use of domestic clays gave only four or five. At present, however, 15, 20, and 25 heats are obtained from an average size crucible, such as No. 80, used in standard rolling-mill practice. By a process of elimination the clays now in use are comparatively few, and a steady improvement is expected in the quality of crucibles. However, the cost of the domestic clay is more than double that of the German clay.

Recent Industrial Uses of Aluminum. F. G. Shull. (*Journal of the American Institute of Metals*, vol. xi, No. 1, June, 1917.)—Aluminum is now so widely used for a variety of purposes in different forms that new applications and new forms of the metal come into use almost unnoticed. The new forms that have acquired commercial importance only in very recent years are: aluminum foil; aluminum bottle caps and jar closures; manufactures involving antogenous welding; die and pressed castings; tubing for store service; rolled rod for machining purposes; and aluminum conductors, steel reinforced.

The aluminum foil industry has grown from practically nothing to a volume of business involving many tons of aluminum annually. Aluminum foil, printed and embossed, is extensively used as a protection and ornamental wrapper for soaps, confectionery, and the like. Plain foil is used to some extent in electrical condensers. The most recent use is for the lining of pulp-board cartons for the packaging of coffee. This combination of package possesses moisture-resisting and oil-retaining characteristics not inferior to the tin can as a coffee container.

The development of a process of welding aluminum by means of the oxyhydrogen and oxyacetylene flame has opened an almost limitless field for the outlet of aluminum. Sheet aluminum of all gauges thicker than one thirty-second of an inch can be readily welded and the seam dressed off so that it is difficult to locate the joint. The difficulties of die-casting aluminum appear to have been overcome, and there are several companies that claim to successfully die-cast this metal. Another quite recent development is the subjecting of sand castings to very high pressures in order to render the metal more dense and to increase its strength; the machining qualities are also improved. High alloy rods are now rolled in practically all commercial sizes. In the past commercial aluminum rod has been largely a drawn product. By the rolling process a more homogeneous material is produced than is attainable by the rolling process, making available a good machining aluminum rod in all commercial sizes for automatic machine and turret lathe products.

Aluminum electric transmission cable, steel-reinforced, has been in commercial use on an extensive scale for the past few years. Steel reinforcement was adopted in order to reduce the greater sag of the line incident to the greater coefficient of expansion and inferior tensile strength as compared with copper cable. It has been found feasible to construct these cables with any standard number of strands and to meet required conditions of strength and sag. To-day many of the most modern transmission lines are built with this cable.

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INDEX TO VOL. 184.

Actinochemistry, Studies in (Custis), 617, 849
Aerial navigation. Theory and operation of Dr. Zahm's propeller computer (Loo), 901
Air, Physics of the (Humphreys), 137, 371, 527, 651, 805
Anderson, Robert J.: The metallurgy of titanium, 469, 637, 885
Aviation engines, Development and progress in (Souther), 509

Book Notices:
  Aldred Lectures on Engineering Practice, 919
  Austin, F. E.: Examples in battery engineering, 323
  Austin, F. E.: Preliminary mathematics, 128
  Beatty, James: The method of enzyme action, 129
  Carnegie Institution of Washington: Ocean Magnetic Observations, vol. iii, 917
  McCullough, E.: Practical structural design, 735
  Marshall, A.: Explosives, Ed. 2, 578
  Popovatz, P.: Notions générales sur les appareils a reaction, 918
  Séjourné, Paul: Grandes voûtes, 325
  Smith, E. F.: The life of Robert Hare, 324
  Stone, I. F.: The aniline color, dyestuff, and chemical conditions, 454
Bridge, The Harahan (Modjeski), 599

Cellulose, The chemistry of (Mork), 353
Chemistry of cellulose (Mork), 353
Color-technology, Physical basis of (Luckiesh), 73, 227
Creighton, Henry Jermain Maude: The deteriorating action of salt and brine on reinforced concrete, 689
Crystals, Formation of, in gels (Holmes), 743
Current Topics, 13, 14, 94, 108, 113, 114, 117, 118, 131, 204, 226, 306, 310, 327, 352, 433, 434, 441, 442, 450, 457, 508, 551, 552, 568, 580, 615, 616, 688, 715, 716, 721, 722, 726, 737, 773, 774, 804, 848, 884, 920, 921
Custis, Horace H.: Studies in actinochemistry, 617, 849

Dynamo electric machinery, Modern (Gray), 15, 205, 409, 553

Eastman Kodak Company, Research Laboratory, Notes, 311, 443, 717, 907
Electron, Radiation and the (Millikan), 337
Engines, Aviation, Development and progress in (Souther), 509
Everglades of Florida, Reclaiming the (Randolph), 49

Florida everglades, Reclaiming (Randolph), 49
Formation of crystals in gels (Holmes), 743
Franklin Institute:
  Library Notes, 124, 319, 451, 575, 732, 914
  Membership Notes, 124, 317, 573, 729, 913
  Officers of the Institute in active military or naval service, 909
  Science and the Arts Committee Abstract of Proceedings of Meetings: June 6, 1917, 123; September 5, 1917, 573; October 3, 1917, 728; November 7, 1917, 911
  Sections, Proceedings of Meetings, 728, 911
  Special Meeting, Proceedings: June 25, 1917, 123
  Stated Meeting, Proceedings: October 17, 1917, 727; November 21, 1917, 910
Franklin Medal, Presentation of the, 95

Gaseous ion, On the nature of the (Loeb), 771
Gels, Formation of crystals in (Holmes), 743
General Electric Company, Research Laboratory, Notes, 445, 721
Gray, Alexander: Modern dynamo electric machinery, 15, 205, 409, 553

Harahan bridge at Memphis, Tennessee (Modjeski), 599
Hitchens, Alfred B.: Maintaining photographic standards, 179

HODGSON, MILLARD B.: The physical characteristics of the elementary grains of a photographic plate, 705
HOLMES, HARRY H.: The formation of crystals in gels, 743
HOSMER, HELEN R.: Submarines in periodical literature, 1911 to 1917, 251
HUMPHREYS, W. J.: Physics of the air, 137, 371, 527, 651, 805

Ion, gaseous, On the nature of the (Loeb), 771

LOEB, LEONARD B.: On the nature of the ordinary gaseous ion, 771
LOO, W. P.: Theory and operation of Dr. Zahm's propeller computer, 901
LUCKIESH, M.: The physical basis of color-technology, 73, 227

Massachusetts Institute of Technology, Electrical Engineering Department, Notes from Research Division, 115, 313, 723
Memphis bridge (Modjeski), 599
Metallurgy of titanium (Anderson), 469, 637, 885
MILLIKAN, R. A.: Radiation and the electron, 337
MODJESKI, RALPH: The Harahan bridge at Memphis, Tennessee, 599
MORK, H. S.: The chemistry of cellulose and its important industrial applications, 353

Naval architecture, Science of (Taylor), 1
NORTHRUP, EDWIN F., and FRANK R. PRATT: Experimental test of the Wiedemann-Franz ratio through a change of state, 675

Oxygen, Dissolved, The vertical distribution of, and the precipitation by salt water in certain tidal areas (Sale and Skinner), 837

Photographic plate, Physical characteristics of the elementary grains of a (Hodgson), 705
Photographic standards, Maintaining (Hitchins), 179
Physical basis of color-technology (Luckiesh), 73, 227
Physics of the air (Humphreys), 137, 371, 527, 651, 805
PRATT, FRANK R., and EDWIN F. NORTHRUP: Experimental test of the Wiedemann-Franz ratio through a change of state, 675
Propeller computer, Zahm's, Theory and operation of (Loo), 901
Publications Received, 130, 326, 455, 579, 736, 919

Radiation and the electron (Millikan), 337
RANDOLPH, ISHAM: Reclaiming the everglades of Florida, 49
Reinforced concrete, Deteriorating action of salt and brine on (Creighton), 689

SALE, J. W., and W. W. SKINNER: The vertical distribution of dissolved oxygen and the precipitation by salt water in certain tidal areas, 837

Salt and brine, Deteriorating action on reinforced concrete (Creighton), 689
SKINNER, W. W., and J. W. SALE: The vertical distribution of dissolved oxygen and the precipitation by salt water in certain tidal areas, 837

SOUTHER, HENRY: Development and progress in aviation engines, 509
Standards, photographic, Maintaining (Hitchins), 179
Studies in actinochemistry (Custis), 617, 849
Submarines in periodical literature (Hosmer), 251

TAYLOR, DAVID WATSON: The science of naval architecture, 1
Titanium, Metallurgy of (Anderson), 469, 637, 885

U. S. Bureau of Chemistry, Notes, 119
U. S. Bureau of Standards, Notes, 109, 307, 435, 569,

Wiedemann-Franz ratio, Experimental test of the (Northrup and Pratt), 675

Zahm's propeller computer, Theory and operation of (Loo), 901

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BOARD OF MANAGERS. Second Wednesday of each month, 3.30 P.M.

INSTITUTE. Third Wednesday of each month (except June, July, August and September), 8 P.M.

SECTION MEETINGS. Thursday Evenings (except week of Institute Meeting), 8 o'clock. October 1 to April 30.

	PAGE
Officers for 1917	x
Membership	xi
Awards and Premiums	xii
Elliott Cresson Medal	xv, xvi
John Scott Legacy, Medal and Premium	xii
Boyden Premium	xiii
Potts and Longstreth Medals	xiv
Howard N. Potts Medal	xvii, xviii
Library	xx
Journal and Indices	vi
School of Mechanic Arts	Fourth cover

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THE JOHN SCOTT LEGACY MEDAL AND PREMIUM

THE City of Philadelphia holds in trust under the legacy of John Scott, of Edinburgh, a sum of money the interest of which is to be used for the encouragement of "ingenious men and women who make useful inventions." **The legacy provides for the distribution of a Medal, inscribed "To the Most Deserving," and Money Premium in the sum of $20 to such persons whose inventions shall merit the same.** The examination of the inventions submitted for the Medal and Premium has been delegated by the Board of Directors of City Trusts, of the City of Philadelphia, to THE FRANKLIN INSTITUTE, and THE INSTITUTE, under the competent assistance of its Committee on Science and the Arts, undertakes to make investigations free of charge and to recommend for the award all meritorious inventions.

Applications should be addressed to the Secretary of THE FRANKLIN INSTITUTE, from whom all information relative thereto may be obtained.

Pursuant to the regulations for the award of the John Scott Legacy Medal and Premium, THE FRANKLIN INSTITUTE, of the State of Pennsylvania, has under consideration favorable reports upon the applications advertised in this JOURNAL. Any objection to the proposed awards, based on evidence of lack of originality or merit of the invention, should be communicated to the Secretary of THE INSTITUTE within three months of the date of notice.

THE FRANKLIN INSTITUTE AWARDS

THE BOYDEN PREMIUM

URIAH A. BOYDEN, ESQ., of Boston, Mass., has deposited with THE FRANKLIN INSTITUTE the sum of one thousand dollars, to be awarded as a premium to

"Any resident of North America who shall determine by experiment whether all rays of light,* and other physical rays, are or are not transmitted with the same velocity." :: :: :: ::

The following conditions have been established for the award of this Premium:

1. Any resident of North America, or of the West India Islands, may be a competitor for the Premium; the southern boundary of Mexico being considered as the southern limit of North America.

2. Each competitor must transmit to the Secretary of THE FRANKLIN INSTITUTE a memoir describing in detail the apparatus, the mode of experimenting and the results; and all memoirs received by him after the first day of January, one thousand nine hundred and seventeen, will, as soon as possible after this date, be transmitted to the Committee of Judges.

3. The Board of Managers of THE FRANKLIN INSTITUTE shall, before the first day of January, one thousand nine hundred and eighteen, select three citizens of the United States of competent scientific ability, to whom the memoir shall be referred; and the said Judges shall examine the memoirs and report to THE FRANKLIN INSTITUTE whether, in their opinion, any, and, if so, which of the memoirs is worthy of the Premium. And, on their report, THE FRANKLIN INSTITUTE shall decide whether the Premium shall be awarded as recommended by the Judges.

4. Every memoir shall be anonymous, but shall contain some motto or sign by which it can be recognized and designated, and shall be accompanied by a sealed envelope, endorsed on the outside with some motto or sign, and containing the name and address of the author of the memoir. It shall be the duty of the Secretary of THE FRANKLIN INSTITUTE to keep these envelopes securely and unopened until the Judges shall have finished their examination; when, should the Judges be of opinion that any one of the memoirs is worthy of the Premium, the corresponding envelope shall be opened, and the name of the author communicated to THE INSTITUTE. The sealed envelopes accompanying unsuccessful memoirs will be destroyed unopened, in the presence of the Board of Managers.

5. Should the Judges think proper, they may require the experiments described in any of the memoirs to be repeated in their presence.

6. The memoirs presented for the Premium shall become the property of THE FRANKLIN INSTITUTE, and shall be published as it may direct.

The problem has been more specifically defined by the Board of Managers, as follows:—

"Whether or not all rays in the spectrum known at the time the offer was made, namely, March 23, 1859, and comprised between the lowest frequency known thermal rays in the infra-red, and the highest frequency known rays in the ultra-violet, which in the opinion of the Committee lie between the approximate frequencies of 2×10^{14} double vibrations per second in the infra-red and 8×10^{14} in the ultra-violet, travel through free space with the same velocity."

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*An award, made during the year 1907, covered the solution of the problem so far as the transmission of the visible and ultra-violet rays is concerned. It has been directed by the Board of Managers that the balance of the fund be retained, to be awarded to such person as shall demonstrate whether or not the infra-red rays are or are not transmitted with the same velocity as the other rays.

THE FRANKLIN INSTITUTE AWARDS

JOURNAL CONTRIBUTIONS

By a resolution of the Committee on Science and the Arts, made October 5, 1910, all papers published in the Journal of The Franklin Institute will be subject to the award of one of the following Medals—

**The Howard N. Potts
Gold Medal**

**The Edward Longstreth
Silver Medal**

The merits of the several papers appearing in the Journal during any current year will be passed upon by a Special Committee appointed for the purpose.

R. B. OWENS,
Secretary

THE FRANKLIN INSTITUTE AWARDS

THE ELLIOTT CRESSON MEDAL

THE FRANKLIN INSTITUTE awards the ELLIOTT CRESSON GOLD MEDAL under the provisions of the Deed of Trust from ELLIOTT CRESSON of the City of Philadelphia, dated the Eighteenth day of February, 1848, on the recommendation of its Committee on Science and the Arts.

"This Medal and Diploma shall be awarded for discovery or original investigation, adding to the sum of human knowledge irrespective of commercial value; leading and practical utilization of discovery; and invention, methods or products embodying substantial elements of leadership in their respective classes, or unusual skill or perfection in workmanship."

For further information address the Secretary of THE INSTITUTE.

THE FRANKLIN INSTITUTE AWARDS

Notice is hereby given that the Committee on Science and the Arts of THE FRANKLIN INSTITUTE has recommended the award of

The Elliott Cresson Medal
TO
Col. Isaac Newton Lewis
Of Montclair, N. J.
FOR HIS
INVENTION
OF THE
LEWIS MACHINE GUN

Any objection to the above recommendation based on evidence of lack of merit should be communicated within three months of the date of this notice to the Secretary of THE FRANKLIN INSTITUTE, Philadelphia.

GEO. A. HOADLEY,
Acting Secretary.

HALL OF THE INSTITUTE
October, 1917.

THE FRANKLIN INSTITUTE AWARDS

Notice is hereby given that THE FRANKLIN INSTITUTE, through its Committee on Science and the Arts, will recommend the award of

THE HOWARD N. POTTS MEDAL
To
DR. A. E. KENNELLY
of the Massachusetts Institute of Technology
Cambridge, Mass.
For his Invention of the
HOT-WIRE ANEMOMETER
and his Application of this Device to the Measurement of Convection from Small Heated Wires

Any objection to the above award based on evidence of lack of merit should be communicated within three months of the date of this notice to the Secretary of THE FRANKLIN INSTITUTE, Philadelphia.

GEO. A. HOADLEY,
Acting Secretary.

HALL OF THE INSTITUTE
November, 1917

THE FRANKLIN INSTITUTE AWARDS

Notice is hereby given that THE FRANKLIN INSTITUTE, through its Committee on Science and the Arts, will recommend the award of

THE HOWARD N. POTTS MEDAL

To

PROF. LOUIS VESSOT KING

of McGill University, Montreal, Canada

For his Improved Method and
Researches in

HOT-WIRE ANEMOMETRY

Any objection to the above award based on evidence of lack of merit should be communicated within three months of the date of this notice to the Secretary of THE FRANKLIN INSTITUTE, Philadelphia.

GEO. A. HOADLEY,
Acting Secretary

HALL OF THE INSTITUTE
November, 1917

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